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ELECTRICITY

THE SCIENCE OF THE NINETEENTH CENTURY



ELECTRICITY

THE SCIENCE OF THE NINETEENTH CENTURY

A SKETCH FOR GENERAL READERS

emma BY
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WITH ILLUSTRATIONS

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PREFACE

THE aim which the writer has proposed to herself in the present little work, is to give such an outline of modern electrical science, as may be readily understood by readers who have no previous acquaintance with the subject, and who, though unable to make a serious study of it, wish to acquire sufficient knowledge to enable them to follow with intelligent interest the marvellous and rapid progress which is being made in this ever-widening field. That a science so comprehensive as that of electricity, should be exhaustively dealt with in a sketch for general readers is out of the question, even though the task had fallen to a far more competent pen than that of the writer. Nevertheless, a sketch sometimes answers a very useful purpose, in awaken-

ing a keen desire for a closer and fuller acquaintance with the truths of which it gives an indication. Should this be the case in the present instance, the writer would be abundantly rewarded for what has been throughout a labour of love. At any rate most persons will agree with her, that to have no knowledge whatever of the striking advances which are being made in all branches of physical science, and especially in those which fall within the scope of "Electricity," is a considerable intellectual loss. It is even more than this, for there is no aid to faith in the Invisible greater than the pursuit of knowledge, which is for ever obliged to penetrate beyond the apparent in order to keep in touch with the real.

In conclusion, the writer desires to express the deep obligation under which she lies to Professor Ayrton, for most valuable assistance in the revision of the proofs, without which she feels that her work would have far less right to be regarded with confidence, than she trusts is now the case. She has also to acknowledge the courtesy of Professor

Silvanus Thompson and his publishers Messrs. Macmillan, in allowing her the use of several illustrations (Figs. 11, 12, 13, and 14) from his work *Elementary Lessons in Electricity and Magnetism*; and of Messrs. Siemens Brothers; Lang, Wharton, and Down; and Batley and Greenwood for the illustrations of dynamos, etc., in Part IV.

EMMA MARIE CAILLARD.

CONTENTS

PART I

STATIC ELECTRICITY OR ELECTRICITY AT REST

CHAPTER I

	PAGE
ELEMENTARY PHENOMENA	1

CHAPTER II

ELECTRICAL MACHINES AND THEIR EFFECTS	15
---	----

CHAPTER III

ELECTRICAL CHARGES — SOURCES OF ELECTRICITY OTHER THAN FRICTION	28
--	----

CHAPTER IV

THE LEYDEN JAR	40
--------------------------	----

CHAPTER V

ATMOSPHERIC ELECTRICITY . . .	PAGE 57
-------------------------------	------------

CHAPTER VI

ATMOSPHERIC ELECTRICITY CONTINUED—THUNDER- STORMS	70
--	----

CHAPTER VII

ATMOSPHERIC ELECTRICITY CONTINUED—DANGERS TO BE APPREHENDED FROM LIGHTNING—MODES OF PROTECTION	91
--	----

PART II

MAGNETISM

CHAPTER I

GENERAL PROPERTIES OF MAGNETS . . .	111
-------------------------------------	-----

CHAPTER II

MAGNETISM OF THE EARTH . . .	127
------------------------------	-----

PART III

CURRENT ELECTRICITY

CHAPTER I

	PAGE
THE GALVANIC BATTERY	138

CHAPTER II

CHEMICAL AND PHYSIOLOGICAL EFFECTS OF THE CURRENT	155
--	-----

CHAPTER III

MAGNETIC EFFECTS OF THE CURRENT	165
---	-----

CHAPTER IV

ELECTRO-MAGNETS	178
---------------------------	-----

CHAPTER V

ACTIONS OF CURRENTS UPON CURRENTS—INDUCTION CURRENTS	185
---	-----

CHAPTER VI

PRACTICAL UNITS OF MEASUREMENT FOR ELECTRIC CURRENTS	197
---	-----

PART IV

PRACTICAL APPLIANCES OF ELECTRICITY

CHAPTER I

	PAGE
MAGNETO-ELECTRIC AND DYNAMO-ELECTRIC MACHINES AND ELECTRO-MOTORS	206

CHAPTER II

ELECTRIC LIGHTING	222
-----------------------------	-----

CHAPTER III

TRANSMISSION OF POWER BY ELECTRICITY	241
--	-----

CHAPTER IV

THE ELECTRIC TELEGRAPH	250
----------------------------------	-----

CHAPTER V

THE TELEPHONE	266
-------------------------	-----

CHAPTER VI

ELECTRO-METALLURGY AND MISCELLANEOUS APPLI- ANCES OF ELECTRICITY	282
---	-----

CONCLUDING CHAPTER

“WHAT IS ELECTRICITY?” 289

NOTE ON THE POLARISATION AND MAGNETISATION
OF LIGHT 300

PART I

STATIC ELECTRICITY

OR

ELECTRICITY AT REST

CHAPTER I

ELEMENTARY PHENOMENA

Definition of Static Electricity—Electrical attraction—Known to the ancients as a property of amber—Gilbert's discoveries—Electrical repulsion—Two opposite states of electrification—Explanation of the terms vitreous and resinous—Superseded by positive and negative—Franklin's theory—Idea of excess and defect acknowledged in modern science—Proofs of its correctness—Analogy between the present state of knowledge of positive and negative electricity and the pre-scientific knowledge of heat and cold—Conductors and non-conductors—Meaning of charge and discharge—Induction—Action of points.

UNDER the head of *Static Electricity* are classed those phenomena which are not caused by a continuous flow or "current" of electricity; and though

they were the earliest known, and are frequently considered as appertaining more or less to elementary knowledge, they yield neither in interest nor importance to the other branches of the science. Of late, special attention has been devoted to them by various scientific experimenters, as modern research leads to the opinion that here, if anywhere, will be found the ultimate solution of some of the many vexed questions surrounding that ever-recurring inquiry, "What is electricity?" Moreover, the eminently practical and useful study of atmospheric electricity belongs chiefly to this branch of the science, which cannot therefore be considered as either barren or uninteresting.

The first electrical phenomenon which claims our attention is that of attraction. Through the whole domain of Nature we are familiar with attraction under one form or another. There is the attraction of the members of the solar system for each other and for their great centre; the attraction between the earth and all terrestrial objects; the attraction between particles (or molecules) of matter, which enables them to form into the larger and smaller masses which we call bodies; lastly, there is the attraction between the elementary chemical atoms leading them to combine and recombine in an endless variety of ways, thus producing all the different substances

with which we are acquainted. And now on the threshold of this latest developed science we are confronted with the phenomenon of attraction again, in a new form and under different conditions certainly, but an old friend nevertheless.

It is supposed that Thales, one of the seven sages of Greece, was the first to discover that amber when rubbed, acquired the power of attracting small light bodies to itself. Be this as it may, the fact was known to his countrymen hundreds of years before the Christian era; and to the Greek word "electron," amber, is due the name electricity.

Two thousand years passed away, and save that jet was found to share the same property as amber, no further advance was made in electrical knowledge. Then in the reign of Elizabeth, so fruitful in progress of all descriptions, Dr. Gilbert of Colchester, whom the Queen had appointed her physician chiefly out of admiration for his acquirements in natural science, added several facts to the one which had so long held the field alone. He found that glass, rock-crystal, gems, sulphur, resin, and various other substances developed on friction the same power of attraction as amber and jet. He called these electrics. Metals and such substances as appeared devoid of any attractive property he termed non-electrics. Gilbert was wrong in this classification,

however, for under suitable conditions, to be presently described, all substances behave as electrics. Gilbert also ascertained that moisture prevented the success of his experiments, and that an electrified body, if set on fire, passed through a flame, or made very hot, lost all sign of electricity.

It is easy to reproduce Gilbert's experiments on electrical attraction. A rod or tube of glass held in the hand and rubbed with a silk cloth, will powerfully attract small pieces of paper, pith, or other light bodies, just as a magnet will attract steel filings or needles, with the difference, however, that whereas in the magnet the force of attraction seems to lie in the two ends, in the rubbed glass it exists all over the surface, so that the pieces of paper will adhere to it anywhere.

Electrified objects possess a force of repulsion as well as of attraction, for in making the above experiment, it will be noticed that in a very short time the pieces of paper or pith fall off the glass, and will not at once be attracted to it again. If, however, while they are in a state of repulsion towards the glass, a stick of rubbed sealing-wax be approached, they immediately fly towards and adhere to that, to be again soon repelled, when the glass will be once more found able to attract them. These phenomena point to the conclusion that bodies can be electrified in

two ways, and that those electrified in the same way repel, while those electrified in opposite ways attract each other.¹ A still more striking proof is afforded by the fact that a couple of rubbed glass rods suspended by silk threads repel each other, and so do two rubbed sticks of sealing-wax, but the glass attracts the sealing-wax and the sealing-wax the glass.

These opposite kinds of electricity were at first called *vitreous* and *resinous*, because it was believed that "vitreous" substances always gave signs of one kind of electricity and "resinous" of the other. This is a mistake, however. Glass rubbed with silk becomes "vitreously" electrified, but rubbed by fur becomes "resinously" electrified. It is evident, therefore, that the kind of electricity manifested depends on some relationship between the rubber and the object rubbed; and it is now supposed that the substance whose molecules are least disturbed by friction shows "vitreous" electricity, and the one where they are most disturbed "resinous." These terms, vitreous and resinous have, however, quite fallen into disuse, and are replaced by *positive* and

¹ It has been proved that two small electrified bodies attract or repel each other with a force varying inversely as the square of the distance between them. This law is known as Coulomb's law, he having been the first to discover it.

negative, known in technical works by the signs + and —. The American philosopher, Franklin, was the first to introduce them, as he was also the first to formulate a theory justifying their use. He supposed that electricity was an invisible and imponderable fluid, existing in a certain fixed quantity in all bodies in a natural state, and that the positive state of electrification showed an excess, and the negative state a defect of this fluid. Whether electricity be or be not a fluid,¹ it is now agreed that it is equally distributed in all bodies which are in a natural state, and that the idea of excess and defect does truly represent the conditions that occur in positive and negative electrification; which is actually the state of excess and which of defect not being, however, a matter of certainty. Practically, positively electrified bodies are considered and treated as those in which there is an excess of electricity.

One proof of the truth of this theory of excess and defect lies in the fact that it is impossible to produce

¹ It is certainly not a fluid in the ordinary acceptation of the term; and in speaking of electricity at all as a separate entity, care must be taken to remember that this is done for convenience sake. We speak of "electricity" as we might speak of a gale or a whirlwind. These have no existence apart from the air of which they are certain states or conditions, and in the same way the various electrical phenomena are caused by conditions not of the air, but of another medium, to which further reference will be made hereafter.

a manifestation of one kind of electricity without causing an equal quantity of the other to appear also. A rubbed glass rod becomes positively electrified, but the silk which rubs it becomes negatively electrified, as can be seen by using it fastened to a glass handle instead of holding it in the fingers. After friction it will be found that both the glass rod and the silk will attract small neutral bodies, and that when these are respectively repelled, those repelled by the glass will be attracted by the silk and *vice versa*.

Many persons seem to find a difficulty in these terms positive and negative, asserting that it is impossible to attach a definite meaning to them, as they convey no clear idea to the mind. There is no doubt, indeed, that, if scientific men really knew what positive and negative electricity are, they would be able to find better names for them. In the meanwhile, as the idea which is wanted to be conveyed is that the two electricities are of opposite kinds, perhaps the terms positive and negative are as good as any that could be put forward. One is almost afraid in the present state of knowledge of venturing the analogy, but possibly the experience which has been gone through in the case of heat and cold may aid the conception of some readers. Cold is the opposite of heat; we now know that it is merely a negation, the absence of heat; people did not always know this.

They supposed that cold was a thing in itself, but this error did not prevent their having a very clear practical conception of what cold was, and of knowing what they must do to neutralise it—produce heat. In the case of electricity the converse of this experience is taking place. We say positive and negative electricity are opposite, and it has been assumed that the positive is the thing in itself, and the negative, the negation, the want of this thing. But this is not true; negative electricity is as real as positive, though no one can pronounce what either is. Pending further discoveries, however, we may have, and electricians have, quite as good a working conception of positive and negative electricity, as the generality of mankind had of heat and cold before science had discovered what these really were. Moreover, it is perfectly understood what must be done to neutralise one kind of electricity—produce the other.

It will have been observed that a silk thread was recommended for suspending the glass and sealing-wax in one of the experiments above described, and that in order to discover the electrical state of the rubber, it must not be handled in use, but fixed to a glass stem. The reason is that some substances are conductors, and some non-conductors of electricity. An electrified body placed in contact with the former

at once parts with its surplus electricity to them, or, if it be in a state of defect, receives from them the electricity needful to restore it to a natural state. Non-conductors, on the contrary, do not allow of the free passage of electricity to and from them in this way, and consequently an electrified body, in contact with them only, cannot return to its normal condition until it has been touched by a conductor. To this latter class belong all metals, impure water, and charcoal. Animal bodies, dry wood, and a few other substances are partial conductors. Oils, silk, porcelain, dry air, and all the so-called "electrics" are non-conductors or *insulators*, thus named because an electrified body surrounded by them is insulated, so far as its electrical condition can be affected by conduction, from every other object; and any body, no matter how good a conductor it may be, will in such a position become an "electric." It is for this reason that Gilbert's division of bodies into "electrics" and "non-electrics" was erroneous. Had he fastened a piece of metal to a clean, dry glass support, and touched it with an electrified body, he would have found the metal acquire the same property of attraction as amber or rock-crystal, for conductors need nothing more than contact at one point with electrified bodies, to become electrified themselves over their whole surface. In the case of non-conductors, on the contrary, every part of the

surface must be separately touched and excited. It is for this reason that friction is necessary in their case, and it will be the more effectual, the more markedly different is the electricity which they develop; for there are stages in this respect, some substances being relatively to each other, much more decidedly positive and much more decidedly negative than others.

A body in an electrified state is said to be "charged," and it is "discharged" when it returns to its natural condition. At the moment of discharge a crackling noise is often heard, and if in the dark small sparks may be seen. The rubbing of a cat's back with the hand will produce these, and also in certain dry states of the atmosphere, combing the hair. Conductors are instantaneously discharged if touched by the hand, or by any object in connection with the earth (*i.e.* in electrical connection by conductors, or partial conductors, such as the floor and walls of a house, for instance); but in the case of a "highly" charged body, it is not always safe to use the hand as a discharger, for the passage of electricity through a living body, produces curious and strongly marked physiological effects, and in some instances the disturbance may be so great as to occasion loss of consciousness, and even of life, as when a person is "struck" by lightning. It is hardly necessary to observe, however, that to produce such

phenomena as these, an apparatus very different from rods of glass and sealing-wax is required; and, in fact, for any but the most elementary experiments an electrical machine is needed. Before entering into any details on this subject, however, some description must be given of what is called *electrical induction*.

An electrified body brought near a conductor has the power of causing the latter to become electrified also, but in the opposite way to itself. Thus, if the former be positively charged, the latter will become negatively charged, and although, if uninsulated, it would be incapable under ordinary circumstances of retaining the electrified state, in the present instance it will do so, as long as it remains in the neighbourhood of the influencing conductor. Such a charge as this is called an *induced charge*, and electricity under such conditions is said to be *bound*, because the close proximity of a charge of the opposite nature, prevents it from availing itself of the open way of escape to the earth, which it would otherwise immediately take. If both the conductors are insulated, the effect produced is different. Suppose the inducing charge to be positive as before, it cannot now give rise to an induced charge which is wholly negative, because there is no means of escape for the positive electricity contained in the conductor which is being influenced. The negative electricity of the latter is therefore

attracted to the end nearest the positively charged conductor, and the positive electricity is repelled to the farther end, so that the two ends are electrified in opposite ways, while the middle appears to be in its normal condition (see Fig. 1). Could the conductor

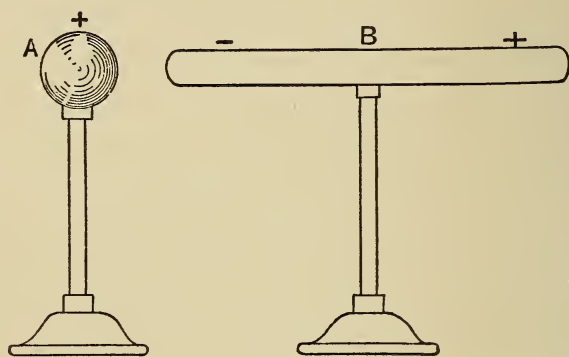


FIG. 1.—Diagram illustrating the charge induced in an insulated conductor B by the neighbourhood of a positively electrified body A

be divided in two, an arrangement often made to exhibit this phenomenon, that half of it which had been nearest the positively electrified body would be found negatively charged, and that which had been farthest from it, positively charged. Charge by induction differs from that by conduction, therefore, in the fact that the former can be caused by altering the distribution of electricity, while the latter requires an alteration of quantity. For instance, if an uncharged insulated conductor were brought near a positively charged insulated body (as in Fig. 1), no electricity would be put into or taken

out of the former, so that if its power of acquiring a charge depended only on an alteration of the quantity of electricity possessed by it, it could not under these circumstances be charged at all. Yet, as a fact, a conductor thus placed does become charged, one end (or side, if it be an upright bar or sheet of metal) positively, and the other negatively. If the influencing body be taken away, the conductor will return to its natural electrical state; but if the former be left, and the latter connected to earth, the conductor will become, as we have seen, negatively charged, and if it be then insulated again, and the positively charged body removed, it will retain its negative charge, because now an alteration has taken place in the quantity of electricity it possesses, some having escaped to the earth, and therefore while insulated it cannot return to its natural condition.

We have hitherto been considering the inducing and induced charges, as separated by a thickness of air great enough to form an insurmountable barrier to their union. Suppose the two bodies to be approached nearer to each other, this barrier may become too slight to resist the strain which is going on; and, just as the pressure of water on a dam may burst the dam, so the accumulated electric pressure bursts the insulating medium, a spark and report take place, and the two bodies are discharged.

The subject of induced charges and the phenomena connected with them is full of interest, and will be referred to at greater length in Chapter IV. Meanwhile, before entering on a description of electrical machines, another fact of great importance must be stated, viz. the action of points on electricity. Franklin was the first to discover this, and he found that their effect is twofold. A pointed conductor both collects a far greater quantity of electricity than one with a flat or rounded surface, and the discharge from it is also much more rapid and powerful.

CHAPTER II

ELECTRICAL MACHINES AND THEIR EFFECTS

General principles of electrical machines—Von Guericke's machine—Cylinder and plate machines—Use of points in electrical machines—Experiments with electrical machines—Electric chimes—Electric windmill—Luminous effects—Electric spark—Brush discharge—St. Elmo's fire—Electrical glow—Discharge through rarefied air and gases—Return shock—Production of ozone—Difference between frictional and influence machines—The electrophorus.

AN electrical machine must always consist of two principal parts, one for producing, and the other for collecting electricity; and in *frictional machines* the quantity of electricity brought into play depends on three things—the extent of surface subjected to friction, the amount of friction used, and the nature of the two substances brought into contact. These should always be chosen so that the one should be the most positive, and the other the most negative possible, relatively to each other. The first frictional machine was invented by a German,

Otto von Guericke, in 1680, and consisted of a large sulphur ball, supplied with a wooden axle, and mounted on a frame. The hand was used as a rubber; and with this simple contrivance Von Guericke succeeded in producing much more powerful effects than had ever been obtained before.

The modern frictional machine is, however, very far superior to this. The surface to be rubbed usually consists of a large glass cylinder or plate,

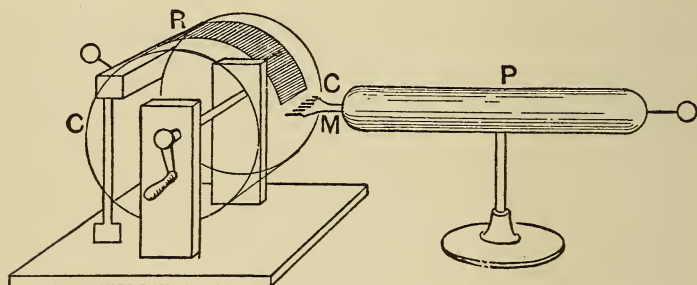


FIG. 2.—Cylinder Frictional Machine. C C, glass cylinder; R, rubber; P, prime conductor; M, metal comb.

provided with a handle by which it can be turned, and the rubber of a leather cushion or cushions, coated with a powdered amalgam of zinc or tin. In front of the glass, but not touching it, is placed the “prime conductor,” which must of course be insulated. It consists in the case of the “cylinder machine” (Fig. 2) of a thick bar of metal, either solid or hollow, placed on glass supports, and provided with a row of small metal spikes at the end nearest the glass cylinder;

and in the case of the plate machine of two bars similarly armed, or of one bent round so that both its ends should be presented to the flat surface of the glass, or else of a large metallic ball, on which a smaller one is often placed. When the handle is turned, positive electricity appears on the glass and negative on the rubbers, which are generally provided with a metal chain, connecting them to "earth" through the floor and walls of the building. The positive charge on the glass induces a negative charge on the nearest end of the prime conductor, whose positive electricity is repelled to the farther end, and is in fact the charge used for the experiments required. The metal points discharge the negative electricity at the near end, in a powerful stream on that part of the glass plate which is opposite to them for the moment, and which consequently returns to the rubbers as the plate continues to revolve, un-electrified and ready to be excited again. This is an important part of the arrangement, because bodies cannot receive an unlimited amount of electricity. When charged up to a certain degree (which varies according to the shape, size, and position of the body), they cannot be further electrified until discharge has taken place;—and the glass plate of the frictional machine would reach its highest effective point, and be incapable of further strengthening the induced

charge on the prime conductor in a very short time, if it were not for the action of the points above described. As the machine is provided with these, however, the induced positive charge at the far end of the conductor becomes very powerful, and long sparks can be drawn from it by presenting another conductor, and experiments performed to demonstrate various electrical phenomena. One sometimes made use of to illustrate attraction and repulsion, is the production of "electric chimes," first invented by Franklin. Three bells are hung from the prime conductor, the two outer ones by wires, the inner one by a silk thread, and having attached to it a metal chain connected with the ground. Two brass balls hung by silk strings are placed between the bells, which, being positively electrified through their connection with the prime conductor, attract them, and are struck by the balls. The latter becoming immediately charged with the same electricity are repelled and attracted towards the uninsulated central bell, against which they strike and discharge themselves, when the outer bells again attract them. Thus they go on alternately charging and discharging themselves, and causing thereby the musical "electric chimes."

Another experiment often shown is the electric windmill, which illustrates the action of points. It

consists of straws or very light metal wires placed crossways and supported on a pivot, with the pointed ends all bent at right angles in the same direction. The whole arrangement is then fixed on the prime conductor of an electrical machine, and becomes strongly electrified, the greatest quantity of electricity collecting at the points, from which it streams off, causing, by the repulsion of the air-particles which it electrifies, a current of air known as an electrical "whirl." The effect of this is to drive the windmill rapidly round in the opposite direction to that of the points. Such a current is often strong enough to blow out the flame of a candle, and can always be felt by placing the hand in its path.

Besides demonstrating very strikingly electric attraction and repulsion, the action of points, and various other interesting phenomena, electrical machines can also produce luminous effects, which are simply reproductions on a small scale of the grand and beautiful natural appearances, caused equally by electricity. The electric spark has already been mentioned, and it is simply a miniature flash of lightning; the very shape of the one, with its sinuous and branching appearance, irresistibly recalling the other, even to the most cursory observation. The electric spark is vivid enough to be seen in broad

daylight, but an equally beautiful though less brilliant effect is the brush discharge, which requires a darkened room in order to be made visible. It is caused by a continuous flow of electricity from some conducting body. To facilitate this from an electrical machine, a piece of wire, filed at one end, is attached to the prime conductor, or, if the latter be highly charged, a bullet will answer the purpose. A fan-like brush of light, whose pointed end rests on the piece of wire or bullet, is then seen, varying in strength according to the nature and amount of charge of the conductor, and being always larger and brighter when the latter is positively than when it is negatively charged. The brush discharge is usually accompanied by a continuous hissing noise, very different from the sharp crack of the spark; but if the conductor be pointed the discharge takes place silently, and is attended by a pale blue light, called an "electrical glow," which becomes a small bright star if occasioned by negative electricity. "St. Elmo's fire," often seen by sailors on the masts of their ships, is an example of glow discharge. It is also sometimes observed on trees, and more frequently on spears and lanceheads, or on the points of bayonets. Such appearances only occur when the atmospheric electricity is in a very disturbed state, most frequently before and during storms.

The usual appearance of the electric spark is,

as has already been stated, that of a miniature flash of lightning; but if it is made to pass through a tube in which the air has been rarefied, a great change takes place. The light assumes a violet tint, and spreads out so as to fill the whole tube, if the latter be not too wide, flickering in such a way as to suggest the idea of undulations travelling in the same direction as the positive electricity. "Geissler's tubes" are generally used for making experiments of this kind. They are simply thin glass tubes, blown into the required shapes and partially exhausted of air; into each end is fused a piece of platinum wire, by means of which the spark is conducted into the tube. Very interesting and beautiful effects are produced by these means. It is found that at the positive pole there is usually a single small bright star of light, while the negative pole is surrounded by a blue or violet-tinted glow, separated from the pole, however, by a small dark space. The more the air is rarefied, the paler does the luminous discharge become, and if exhaustion is carried to a sufficiently high pitch the whole tube becomes dark. The darkness appears to proceed from the negative pole, as with every increasing stage of exhaustion the dark space between it and the glow of light grows wider. Sometimes all the light in the tube breaks up into successive patches

or *strice*, as they are called, which vibrate to and fro. These striæ have their origin at the positive pole, and commence at a certain pitch of exhaustion, increasing in number as this increases for some time, when if the air or gas be still further rarefied they grow fewer and thicker. The colour of this luminous discharge is found to vary with the kind of gas through which it passes, and also with the nature of the metallic conductors forming the opposite poles. The former cause is most active when the discharge is weak, and the latter when it is powerful. To observe the colour it is best to use narrow tubes. The light is seen to be of a violet tint in air and oxygen, blue in nitrogen, red in hydrogen, and white in carbonic acid.¹

The effect produced by the metal conductors on the colour of the luminous discharge seems to be due to the vaporisation of small particles, owing to the intense heat developed at the respective poles, and indeed along the whole passage of the spark. This heat is so great that fine wires may be made red hot and even fused by it, presenting an analogy to what sometimes occurs in the case of lightning and lightning conductors. The latter, especially in former days when their proper construction was less well

¹ Sparks from induction coils are more frequently used in these experiments than those from electrical machines. See p. 192.

understood, have not infrequently been melted by a violent discharge.

Persons standing near a powerful electrical machine at work often experience a curious sensation, as though a cobweb were spread over the face, and when it is discharged they perhaps feel a "shock"; this is the same thing as what is known as the "return shock" in the case of a lightning flash, and is caused by induction.¹ In both cases the presence of a charged body (be it cloud or electrical machine) causes a charge of opposite sign in other bodies near it, and when it is discharged they also discharge themselves, and in the case of a living being a "shock" is felt. There is also invariably a peculiar and powerful odour in the neighbourhood of an electrical machine in action, due to the presence in large quantities of ozone, which is a modified and, so to speak, condensed form of oxygen, and to which further reference will be made in a future chapter.

The machines of which a slight description has been given above, though partly owing their efficiency to induction, are known by the name of frictional machines, since it is friction which generates and keeps up the supply of electricity. There are, however, other machines much more powerful, and greatly

¹ It appears, however, that other causes may be at work to produce the return shock. See p. 79 note.

used in laboratory experiments, which are wholly dependent on induction; and just as the parent of the perfected frictional machines of modern days was the homely apparatus of Otto von Guericke, so the progenitor of the powerful "influence" machines is the simple and, to all students of electricity, familiar little instrument known as the *electrophorus*.

As its name indicates, it is a contrivance for carrying electrical charges from one place to another.

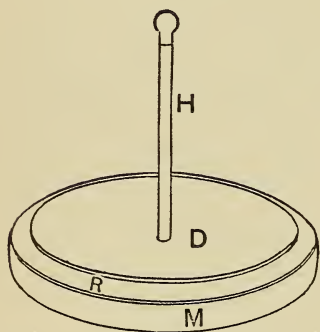


FIG. 3.—Electrophorus. M, lower metal plate; R, resin or ebonite disc; D, upper metal plate attached to H, insulating handle.

It consists of three parts, two metal discs or plates, one of which is provided with a glass handle, and a slab of resin or ebonite—usually the latter in modern instruments—which fits into the lower plate (see Fig. 3). The ebonite is electrified by friction with wool or fur, its charge being of course negative. The

upper metal disc is then placed upon it, but does not actually touch more than three or four points of the surface, from which it is separated by a very thin film of air, so that it is really in the position of an insulated conductor in the close neighbourhood of an electrified body, and becomes positively charged by induction, the negative electricity being repelled to

the outer surface. The disc is then touched with the finger, or in some way momentarily connected to earth (so that the negative electricity escapes), and being lifted away from the ebonite by means of the insulating handle, is found to have retained a positive charge powerful enough to permit a good-sized spark to be drawn from it, if another conductor be presented to its surface. As the disc was electrified by induction, no part of the original charge of the ebonite has been taken away, and the latter will be capable of recharging the disc an indefinite number of times, without requiring to be again electrified itself. The simplest way of understanding the action of the electrophorus is to bear in mind, that when the ebonite has received its negative charge, and the metal plate attached to the glass handle is placed upon it, both this plate and the one under the ebonite, have positive charges induced on the surfaces facing the ebonite. Therefore, if either plate be connected to earth, and then insulated and removed, it will retain a positive charge (see p. 13). The charge thus communicated to the electrophorus can be conveyed to any conducting body and given up to it by contact, and if the process is repeated often enough, an insulated conductor may thus become electrified to a high degree. In an ordinary electrophorus there is no way of giving rise to, or increasing the original charge on the ebonite

except by friction. In the accumulating influence machines, referred to above, however, which are

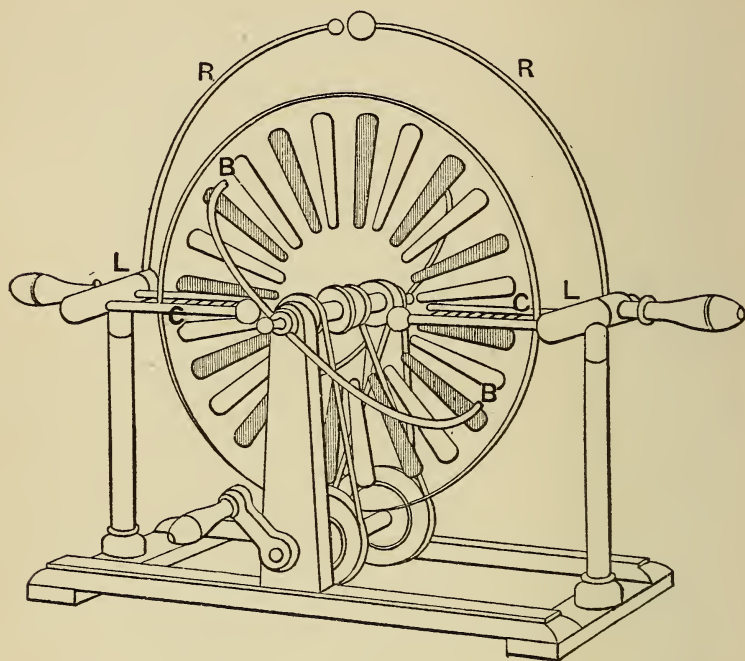


FIG. 4.—Wimshurst Influence Machine. This machine consists of two circular glass plates, about $\frac{1}{8}$ of an inch apart, and made to revolve in opposite directions when the machine is at work. Each of these glass plates has attached to the outside a number of metallic sectors arranged like the spokes of a wheel. These sectors perform the office of both inductors and carriers, the carriers on one plate acting as inductors to the carriers on the opposite plate. The machine is provided with two discharging rods *R R* (whose knobs must be separated, and the rods themselves connected to the insulated brass cylinders *L L*, when the machine is to be used for charging any body), four collecting combs (two of which, *C C*, are seen in the figure), and two curved brass rods *B B* (one only represented), which carry at their ends small wire brushes connecting the pair of carriers which are at the moment under the influence of the inductors.

made on the principle of the electrophorus, the initial charge is produced in quite a different way

(explained on page 33), and is increased by a system of action and re-action, which enables influence machines to produce effects, far exceeding in magnitude, any to be obtained by the same amount of mechanical labour from frictional machines. The best known influence machines are the Holz and the Wimshurst. The latter is represented in Fig. 4, but its principle cannot be understood until the explanation respecting *potential*, and *difference of potential*, given in the ensuing chapter has been read (p. 31).

CHAPTER III

ELECTRICAL CHARGES—SOURCES OF ELECTRICITY OTHER THAN FRICTION

Seat of "charge"—Biot's experiment—Faraday's experiment with conical bag—Proof-plane—Distribution of electricity on the surface of a sphere—On other surfaces—Density—Cause of charge—Analogy with dammed-up water—Importance of insulating medium—Capacity of bodies—Potential—Detection of charges—Gold leaf electroscope—Slightness of causes producing charge—Measurement of charges—Torsion balance—Coulomb's law—Electrometers—Difference between force and quantity—Various sources of electricity—Electricity not made but caused to manifest itself by disturbance of equilibrium—Analogy with air.

HITHERTO nothing has been said as to the seat of the charge in an electrified body, though the expressions used may have led to the true inference that it resides wholly on the surface. The interior of a conductor is never found to be electrified when electricity is at rest on it. The outer surface alone is capable of "charge."

This has been proved in a variety of ways. One experiment known as Biot's¹ is to electrify an insul-

¹ It was really first performed by Cavendish.

ated metal ball, over which two hemispheres also made of metal, and provided with glass handles can be fitted. So long as the hemispheres do not touch the ball, it retains its electrified state, but the most momentary contact suffices to transfer the whole charge to the outer surface of the hemispheres, the ball being left without a trace of electricity. Another experiment, devised by Faraday, is to electrify a conical linen bag placed on an insulating stand, and provided with silk strings by which it can be turned inside out. When electrified the charge is ascertained to be on the outside; the strings are then pulled, so that what was the inner becomes the outer surface, and the charge is again found to be on the outside, showing that the electricity must have passed from one surface to the other, in order to retain its outside position.

A third way of proving the same fact is by means of a little instrument called the proof-plane. This is a very small metal disc or bead fastened to a glass stem, and which when placed in contact with an electrified body receives a small part of the charge. If this disc be carefully inserted in a hollow metal ball which has been electrified, and be made to touch the inner surface, no trace of electricity is communicated to it, but it becomes charged directly by momentary contact with the outer surface.

A sphere sufficiently far removed from other conductors to be practically outside the range of their influence, is the only body over whose surface electricity distributes itself with perfect equality. Bodies of any other shape will have more electricity on some parts of their surface than on others, and at every point or edge it will collect in greater quantities than anywhere else. The quantity of electricity per unit of area (*i.e.* per square centimetre,) at any given spot on the surface of a body, is called the *density* of electricity at that spot, and wherever the greatest density is, there also will the greatest effort be made to escape, and there will the discharge, if there is one, take place.

The fact that charges reside only on the surface of bodies, points to the conclusion that the real seat of the effects produced, is not after all the conductors, as was formerly supposed, but the insulating medium by which they are surrounded. If all bodies were perfectly conducting, there could be no possibility of disturbance in electrical equilibrium, because electricity could pass freely to and from all, thus finding its own equality of distribution, as water finds its own level. A "charge" occurs because at the surface of a conductor the electricity meets with a medium into which it cannot pass, and it as it were piles itself up so as to acquire strength to break

through. Dammed-up water and an electric charge are much in the same situation. Both are unnaturally confined, both will escape from confinement if they possibly can; the water either by overflowing or bursting its banks, the electricity also by overflow, *i.e.* leakage, or by discharge, *i.e.* by suddenly bursting the imprisoning medium. Faraday was the first to point out that the study of the insulating medium, was in fact of far greater importance than that of conductors; and since his time the attention of electricians has been much more turned in this direction, to the great benefit both of theoretical and practical knowledge.

It is evident that all electric charges cannot be alike; the same body may receive either a small or a large charge. Again, different bodies have what is called a different *capacity* for charge, *i.e.* some are capable of accumulating a larger quantity of electricity than others. The capacity of a body depends partly on its size. The larger it is, *i.e.* the greater extent of surface it possesses, the greater the quantity of electricity it can receive; but capacity is also affected by other causes to be mentioned hereafter.

The electrical condition of a body compared with that of some other body or bodies is called its *potential*, and a charge may be one of either high or low potential. A small body receiving a certain

amount of electricity may be at a high potential; a much larger body receiving the same amount of electricity would be at a low potential; and the tendency of electricity is always to flow from a body at high potential to one at low potential, so as to equalise its distribution, just as the tendency of water is to flow from a high to a low level for the same reason. In fact, it is often said that potential is to electricity what level is to water, and as in measuring elevations the sea-level is taken as zero, so in measuring differences of potential, or differences in electrical level, the surface of the earth, which is nevertheless always slightly electrified, is arbitrarily taken as zero. Another analogy between level and potential may be permitted. Falling water does work in passing from a higher to a lower level; electricity in passing from a higher to a lower potential does work also, and in charging a body the same kind of operation is performed as in pumping up water. Work is expended in order that the capability for work may be produced.

The potential of a conductor may be varied in one of three ways: (1) by altering its charge (increasing the charge, increases, diminishing the charge, diminishes the potential); (2) by altering its shape without altering its charge (because change of shape occasions a change of distribution of electricity); (3) by altering

its position (because the electrical condition of a conductor is always affected by that of other bodies in its neighbourhood, on account of the mutual inductive action which takes place between them). The potential of any given body therefore depends on its shape, size, and position with reference to other bodies.

It is now possible to explain what is the cause of the initial charge in an accumulating influence machine. It arises from the very slight potential difference existing between parts of the machine called the *inductors*, which fulfil the same office as the ebonite in the case of the electrophorus. This potential difference is increased by the action and re-action between the *carriers* (which correspond to the removable metal plates of the electrophorus,) and the inductors. The carriers have charges induced in them by the potential difference existing between the inductors. They are then made to give up these charges to the inductors by contact, with the result that the potential difference between the latter is increased, and their consequent inductive action on the carriers made stronger, so that they are able to receive and convey more powerful charges. Since this process can be indefinitely repeated, a very small potential difference rapidly becomes a very large one, and the machine consequently able to produce extremely powerful effects.

In electrical study and practice it is often of great importance to determine what the exact potential of a body compared with some other body (often the earth) is. In order to fulfil this purpose instruments called *electrometers* are used.

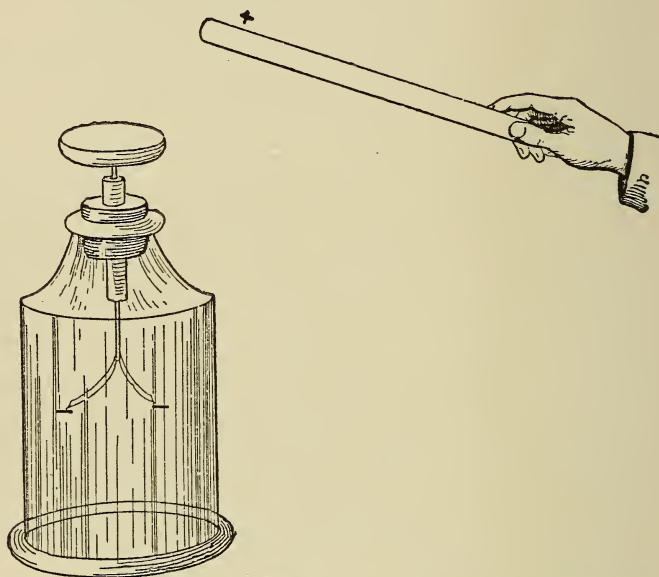


FIG. 5.—Gold Leaf Electroscope, showing divergence of leaves at the approach of a rubbed glass rod.

The most familiar is the “gold leaf electroscope.”¹ It consists of two strips of gold leaf placed inside a glass jar, and suspended by a wire which passes through a glass tube fixed in the cork, stopping the

¹ An *electroscope* is intended really to detect the presence and indicate the kind of electricity, but the gold leaf electroscope, though it can do this, is primarily a measurer of potential differences, and therefore an *electrometer*.

mouth of the jar. This wire terminates in a knob or else supports a flat piece of metal. When the gold leaves are unelectrified they hang straight down, touching each other; but the moment any charge is communicated to them they diverge, being similarly electrified (see Fig. 5). This instrument is so sensitive that the smallest charge imparted to it, is made apparent. The chips cut from a cedar pencil and allowed to fall on the metal plate, are seen to be electrified, for as they touch the plate the leaves diverge. A rubbed glass rod approached within two or three feet from the instrument produces a marked effect, the gold leaves being then charged by induction. In the old form of this instrument, however (as depicted in Fig. 5), difficulties arose from the fact that if the glass shade were made as insulating as possible, the gold leaves would feel the influence of *any* outside neighbouring body, and therefore there could be no certainty with what the one under test was being compared. On the other hand, if the insulation of the glass shade was less carefully attended to, then the damp or dust collected on its outside would bring the latter to about the same potential as that of the earth, with which therefore the body under test could be approximately compared, but then the imperfect insulation rendered it probable that directly the body was connected to

the knob of the electroscope, it would be wholly or partially discharged,—and therefore no longer of importance to test. Both these objections to the gold leaf electroscope have been overcome in the modern form of the instrument, devised by Professors Ayrton and Perry, in which the interior of the glass shade is coated with strips of tin foil, leaving only enough bare space to allow the gold leaves to be visible, and thus screening them from the influence of outside bodies, while the wire supporting the gold leaves passes through the top of the instrument, without touching it, thus greatly facilitating insulation.

It is curious to think that while the most advanced scientists are still unable to pronounce with any certainty what electricity is, they, and indeed every practical electrician can measure this mysterious agent with the same unfailing accuracy that a tradesman can weigh out a pound of tea. Given any known combination of circumstances, and they will foretell precisely the behaviour of electricity under those circumstances. There is a regular system of electro-static units which need not be entered into here. They are based like the practical electro-magnetic units, of which a list and explanation will be given in a subsequent portion of this work, on the centimetre, gramme, and second as the units of length, mass, and time respectively.

As yet no source of electricity has been mentioned save friction, but there are many others, among the most important of which are magnetism, chemical action, heat, and the contact of dissimilar substances. The two first of these will require special chapters devoted to them, and the subject of thermo-electricity also falls more properly under the head of current electricity.

With regard to the contact of dissimilar substances, Volta was the first to discover that two metals allowed to touch each other become feebly electrified in opposite ways, there being a much greater difference of potential¹ between some than between others. Thus when zinc is placed in contact with lead, it becomes slightly positive relatively to the lead, in contact with copper it is much more decidedly positive, and in contact with platinum the difference of potential is very considerable indeed. Volta arranged a series of metals (to which a few have been added since his time), in which every metal becomes positive, if placed in contact with one lower on the list. This list is given at the end of the chapter, as it may be found useful for reference.

Two dissimilar liquids in contact also show a

¹ For convenience sake a positively electrified body is usually said to be at high potential and a negatively electrified body at low potential; but this is not really accurate, for there can be a high negative potential as well as a high positive one.

difference of potential, as do a liquid and a metal, and a cold and a hot metal.

Other sources of electricity will be treated of as occasion requires, but it is worth while to notice how entirely we are so far justified in the conclusion, that electricity is not made by the exciting cause, whatever that may be, but only obliged to manifest itself by being forced into an unnatural condition. One evidence of this lies in the fact that neither positive nor negative electricity can be produced alone, an equal amount of the opposite kind is invariably forthcoming also. Another proof of the same thing is the possibility of charge by induction, in which the electrified state can be produced by mere influence, without any alteration in the quantity of electricity present. These considerations compel us to the belief that whatever electricity may be, it is universally present, though we are often unconscious of the fact. Nor is this in reality a strange circumstance. It is probable that if the air were always in a state of perfect calm we should never know that such a thing as air existed.¹ We are rendered conscious of it by disturbances in its equilibrium, which cause the various winds. The same observation seems to apply to electricity. Some cause disturbs its equilibrium, and we then have too much of it in

¹ See *Modern Views of Electricity*, by Dr. Oliver Lodge, F.R.S.

one place and too little in another, and the effort to restore equilibrium makes us conscious that electricity exists ; but when it is only present in its natural state, *i.e.* in one of perfect equilibrium, we do not know it is there.

List of metals in which every one is electro-positive to that next in order—

+ Sodium	Copper
Magnesium	Silver
Zinc	Gold
Lead	Platinum
Tin	Carbon —
Iron	

CHAPTER IV

THE LEYDEN JAR

Importance of Leyden jar—Description—Electrical forces act across dielectrics—Capacity of conductors increased by proximity of opposite charge—And by earth connection—Definition of condenser—Discovery of Leyden jar by Cuneus—Method of charging and discharging—Residual charge—Important part played by dielectric—Real seat of charge—Bursting of jars—Battery of jars—Oscillatory nature of Leyden jar discharge—Further analysis of discharge—Sparkling distance—Cause of its increase—Analogy with recoil—Cause of damping out and slackening of vibrations—Experiments by Dr. Oliver Lodge—Discharge of jar through circuit—Wheatstone's experiment—Velocity of discharge—Mechanical effects—Lichtenburg's figures—Magnetic effects of discharge—Physiological effects—Chemical effects.

THIS name is familiar to all, not excepting those "born in pre-scientific days," for even then there were occasional quasi-scientific lectures given at schools and at country towns, at which the Leyden jar, thanks to its "shock"-giving capabilities often played a prominent part, though it is doubtful whether the audience, or even in many cases the

“lecturer” himself, understood the principle of its action. To electrical students of the present day this simple and, as some might suppose, antiquated apparatus is full of interest, for it involves facts as important and as wide-reaching as any of the more famous practical appliances of modern days; and only so recently as March 1889 Dr. Oliver Lodge in a discourse delivered at the Royal Institution, exhibited by means of the Leyden jar an entirely novel series of experiments illustrating some of the latest discoveries in electrical science.

The ordinary Leyden jar is a common glass jar, coated inside and outside to about four-fifths of its height with tin foil, and provided with a lid of dry well-varnished wood, through which passes a thick brass wire, terminating on the outside in a metal knob, and communicating inside with the tinfoil, lining the inner surface of the jar. There are therefore two conductors, the two tinfoil coatings in presence of each other, separated by an insulating substance, *i.e.* the glass jar. In Chapter I. it has been stated what happens when two conductors, one of which is electrified, are in close neighbourhood and divided by the air. An induced charge in the originally unelectrified conductor is the result. If instead of air a sheet of glass were placed between the conductors, the induction would occur just the same,

for glass and all insulating substances allow the electric forces to act across them, for which reason the name *dielectrics* is given to them. Though, however all insulators are dielectrics, all are not equally good in this respect, nor does the best insulator make the best dielectric. Dry air is a more powerful insulator than glass, but it is not so good a dielectric, *i.e.* the inductive force does not act so freely across it. This is fortunate, as if air were as good a dielectric as glass our thunderstorms would be more violent and frequent. Substances which serve well as dielectrics are said to possess a high *inductive capacity*.

It has already been stated that charges of opposite nature in presence of each other are bound. They cannot avail themselves of the road of escape to the earth, even if open, because of the attraction each feels for the other. It follows from this, and has been proved by experiment, that the capacity of a conductor is increased by having near it another conductor oppositely charged. The two charges act on each other so strongly, they are (if the expression may be permitted) so occupied with each other, that they produce hardly any effect on surrounding objects, and are barely influenced by them. A conductor thus situated appears to be at a very much lower potential, than it would if it were removed from the

neighbourhood of the oppositely charged body. If it is desired to raise the potential of a conductor when in presence of one oppositely charged, to the same degree as when not so, a very much larger quantity of electricity will be required, which is saying in other words that the capacity of the conductor has enormously increased.

There is another circumstance which increases capacity. This is if the charged conductor be in presence of one not only oppositely charged, but connected to earth, for, supposing the latter to have an induced negative charge, it will if connected to earth lose some of its positive electricity, the negative charge becoming in consequence much stronger, and attracting yet more positive electricity into the conductor whose charge is of this sign. Consequently, a conductor close to one oppositely charged which has an earth connection, is capable of accumulating very large quantities of electricity, and an apparatus made on this principle and for this object is called an *accumulator* or more often a *condenser*. Having said thus much, we may return to the Leyden jar, which was the earliest known and is one of the best of all condensers.

Its name is derived from the place where it was first invented, or to speak more correctly, discovered, which happened by pure accident. In the year 1746

Cuneus, a scientist of Leyden, wished to electrify some water. With this object he placed the liquid in a wide-mouthed glass vessel which he held in his hand, allowing a metal chain from the conductor of an electrical machine to dip into the water. After some time, thinking the latter must be sufficiently electrified, he took hold of the chain to lift it out of the vessel, when to his intense surprise he experienced a severe shock, which so terrified him that he let fall the vessel, and wrote a few days afterwards to Réaumur that he would not expose himself to the same sensation again for the crown of France. What had really happened in the case of Cuneus and his glass vessel, was that he had unwittingly turned it into a condenser, the water serving as one conductor, his own hand as the other, and the glass of course as the dielectric. When therefore he connected the two conductors by taking hold of the metal chain with his other hand, a discharge immediately took place through his body, occasioning the shock which so alarmed him, and which may be felt by any person who uses his hand to discharge a Leyden jar.

The ordinary method of charging is as follows.—The jar is taken in the hand and its knob placed against the prime conductor of an electrical machine positively charged. Through the metal knob and

wire positive electricity passes to the inner coating of the jar, and induces negative electricity on the outer coating, driving away the positive electricity of the latter to earth through the hand and body of the experimenter.¹ A stronger negative charge is the consequence, and its increased power of attraction draws more positive electricity into the inner coating, and the former process is repeated. The charging may be continued till the jar is electrified to the highest amount of which it is capable without bursting the glass, a contingency which always has to be guarded against. When charged, large sparks may be drawn from the jar by presenting the knuckle, or one of the ends of a "discharging rod" to the knob,—a discharging rod being simply a metal rod provided with glass handles, and jointed in the middle to allow of the two ends (which are knobbed) approaching each other. After the spark has been drawn the jar is found to be discharged or rather apparently so; for if it be left some little time, and the discharging rod be then presented to it, a small spark may be drawn from it, showing that the jar could not have been entirely discharged by the first large spark. This second spark, which can never

¹ An insulated Leyden jar will not charge, because the potential of the two coatings rises equally, unless of course the coatings are connected, when they can be charged as one conductor with electricity of the same sign.

be obtained immediately, is due to what is called the "residual charge." Its return may be hastened by tapping the jar, which seems to show that its cause must lie in the molecules of glass not being able to return immediately to their natural condition

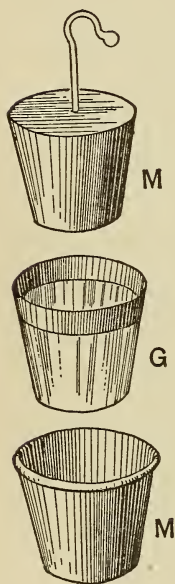


FIG. 6. — Leyden jar with removable coatings. M M, metallic cases; G, glass jar.

after the strain put upon them, and its amount depends to some extent on the length of time the jar has been left charged, but also on the kind of glass of which it is made. In an air-condenser (a condenser formed by two conducting surfaces separated by air,) there is no residual charge. This shows at once that a very important part is played by the dielectric; and a still more striking proof of the same thing is given by the fact that the real seat of the opposite charges in a Leyden jar is not the tinfoil coatings, but the inner and outer surfaces of the jar itself, as has been proved by means of a jar with removable coatings (Fig. 6). If after

charging the latter are taken away, they are found not to be electrified; on being replaced their charges at once return. This seems to explain the reason of a charge being always apparently on the surface of a conductor; in reality its seat is on that surface of the

dielectric which touches the conducting surface, and not on the latter. It is the effort of the electricity to enter the dielectric medium which causes the "charge," viz. an accumulation of electricity unable to disperse itself. The Leyden jar is in truth a type of all "charge" and "discharge" phenomena, and in particular its conditions, as we shall hereafter see, are precisely those obtaining between two thunderclouds, or between a thundercloud and the earth. It is this typical character which invests it with so great an interest. A third fact concerning it which has already been mentioned, that if too highly charged it bursts, *i.e.* a hole is pierced in the glass dividing the inner and outer coatings, points to the true explanation of what happens to a dielectric placed between two charged conductors. It is thrown into a state of strain, which if too great causes it to break. In the case of air such a rent is self-mending; with glass of course it remains, and a Leyden jar thus pierced is rendered useless. An instructive and significant fact is that a vacuum acts as a dielectric, clearly showing that the strain can exist without the presence of ordinary matter. The conclusion is therefore justified that it must primarily take place in the ether,¹

¹ The name given to an imponderable, tenuous, and highly elastic medium which pervades all space and interpenetrates all matter, and through which heat, light, and electrical energy are propagated by means of radiation. According to the latest scientific theories,

and be by it communicated to air, glass, and other dielectrics.

If a Leyden jar be made sufficiently large, it is evident that it might accumulate an enormous quantity of electricity, but as very large jars are found inconvenient in practice, it is more usual to connect them together in such a way that they can, if desired, be all discharged at the same moment. Such an arrangement is called a "battery" of jars, and, if the latter be of high capacity, is a very powerful source of electricity.

The spark from a Leyden jar is of infinitesimal duration, lasting only a small fraction of a second, and it was formerly supposed to be due to a single discharge. Such is, however, by no means always the case. When the spark is examined by means of a very rapidly rotating mirror, it is often seen to be serrated, proving that the discharge which causes it is not a solitary rush, but a number of surgings backwards and forwards, that the discharge is in fact *oscillatory*; and the rapidity of these oscillations is such, that some hundreds of thousands take place during the minute fraction of time which limits the duration of the spark. This fact throws light upon

all electrical phenomena are caused primarily by strains and stresses in the ether. Further reference will be made to this subject in the concluding chapter of the present work.

one which would otherwise be inexplicable, viz. that a Leyden jar is most inclined to burst, not, as would be naturally supposed, before, but at the moment of discharge,—no doubt because the glass, though able to bear the continued strain in one direction (which is the condition of things in a “charge”), gives way when that direction is reversed and re-reversed with such inconceivable rapidity, its force of recovery (or elasticity) not being equal to the demand made upon it.

The fact of the discharge of a Leyden jar being oscillatory does not at first sight appear to be of any great importance, but when we recollect that all charge and discharge are like those of a Leyden jar, we begin to understand that such a discovery as this is of the highest moment, and must be intimately connected with any true theory of the nature of electricity.

It is not necessary for the discharge of a Leyden jar to take place by means only of the discharging rod; there are many other ways in which it can be effected, some of them very interesting and instructive; but there is one way in which neither it nor any condenser arranged in the ordinary way with one coating connected to the earth will discharge, and that is by means of a continuous flow of electricity to the earth or to another conducting body.¹ If a

¹ It is to be observed, however, that if a discharging rod were applied with great suddenness to a charged condenser of consider-

wire is fastened to a single charged conductor, and then connected to earth or to another conductor, a flow of electricity begins and continues till the two bodies are at the same potential, just as water contained in two vessels connected together, one of which is fuller than the other, will flow from the fuller to the more empty vessel, till the water in both is at the same level. But, as we know, a Leyden jar is not a single charged conductor, it consists of two conducting surfaces separated by a dielectric, and it has two charges, not one charge, which being thus in presence of each other are bound and will not flow away to the earth. When the discharge takes place therefore, it is on account of the strain to which the dielectric separating the two electricities is subjected, breaking it down, so that either a hole is pierced in the glass, or a rent made in the air between the knob of the jar and the discharging rod. It is in this kind of discharge that a spark passes, and the distance it can overleap is called the *sparkling distance*. This increases with the difference of potential. A much larger spark can be drawn from a Leyden jar when highly charged, so that the coatings relatively to each other are very positive and very negative, than when feebly charged. It is, in

able size, much of the discharge would then take place in the form of a flow between the two coatings.

fact, difference of potential which produces the spark at all, and consequently the greater that difference is, the greater the sparking power will be. The well-known mechanical phenomenon of recoil helps to explain this. The rebound of a spring which has been stretched to its utmost extent is very much greater than when it has been only slightly stretched; and this analogy may help us also to a clearer idea of the oscillatory nature of discharge. The spring when let go, flies beyond its natural position and then back again, overshooting the mark on the other side, so that before it settles down a series of oscillations takes place. A plucked violin string gives an example of the same thing; and it is what frequently happens in the case of the Leyden jar. Its discharge is then a series of partial discharges, caused by the electricity overshooting the mark and swinging back again, just as the spring or the violin string overshoots the mark and swings back again. The inner coating of the jar at the instant the discharge begins is positive, it then becomes momentarily negative, to return again to positive, and then back to negative, the charge becoming feebler with each vibration till it is entirely dissipated, just as the oscillations of the spring become smaller and smaller in range, till they cease altogether and it is at rest. Clearly the greater the resistance the spring has to encounter in making these move-

ments, the fewer they will be and the sooner they will cease; and we may illustrate the same fact by a pendulum. In air it will oscillate for a considerable time. In treacle it will not oscillate at all, but simply return to its position of equilibrium with a slow sliding motion. The same thing is true of a Leyden jar discharge. The electricity may encounter very little resistance on its road, or it may encounter a good deal. In the former case the oscillations will be many and rapid, in the latter few and slow, and it is even possible, as in the case of the pendulum in treacle, to put a stop to them altogether. The same effect as that of resistance may be produced by weighting a spring. A heavy violin string vibrates much more slowly than a light one, and something analogous to the adding of weight, but which cannot here be explained, may be done in the case of electricity.¹ Acting on this principle, Dr. Oliver Lodge was able to show some very remarkable experiments at the Royal Institution in March 1889. He brought down the number of vibrations in a Leyden jar discharge from their usual frequency of about 1,000,000 a second to 500 a second, with the result that the sudden sharp crack of the spark was changed into a distinct musical

¹ It is accomplished by increasing what some electricians call the "self-induction," and others the "electro-magnetic inertia" of the circuit. See pp. 151-152.

note, and the line of light was seen by the audience to be quite coarsely serrated by means of a mirror revolving only four times a second.¹

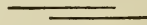
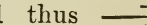
It has already been said that a Leyden jar can be discharged in various ways: for instance, instead of a discharging rod being used, and one end made to touch the outer coating, while the other is approached close to the knob connected with the inner coating, wires may be fastened to each of the coatings and made to pass round a considerable space, or coiled many times on themselves, before their respective free ends are brought near together. When this is done, however, a spark passes between the two, just as it does between the discharging rod and the knob of the jar. Such an arrangement is called a *circuit*, and several intervals may be left in it, all of which the spark will overleap, provided their united length does not exceed that which it could pass at one jump.

Apparently the discharge takes place as instantaneously when the electricity has to travel through many yards of wire before arriving at "sparking distance" as when the discharging rod is used. This is not really the case, however; and by a celebrated experiment (which, broadly described, consisted in

¹ For a detailed report of the above experiments and the discourse which they illustrated, see *The Electrician* for 15th March 1889.

connecting each of the coatings of a Leyden jar with a considerable length of wire, and arranging three small intervals side by side across which sparks had to pass)¹ Sir Charles Wheatstone determined the velocity of transmission through copper wire to be at the rate of 463,133 kilometres, or 288,000 miles a second. Other experimenters have, however, obtained different and very much slower rates, and in any case it must not be supposed that this experiment really proved anything at all about the "velocity of electricity." It simply showed that through a conductor of given resistance and capacity, a certain electric effect took a definite though infinitesimal time to travel, which would not be the same through a conductor differing in either, or both of these respects.

The heating and luminous effects of discharge have been already mentioned. Its mechanical effects are of equal importance and interest. The electric

¹ The test was as follows: The central interval was that which the spark had to pass *after* the two electricities had made the journey through their respective wires; the side intervals they encountered almost immediately. If the transmission had been instantaneous, the sparks examined in the rotating mirror would have presented three parallel lines. Instead of this their appearance was thus  when the mirror turned from right to left, and thus  when it turned from left to right, showing that the central spark began after its companions, and also proving the double flow, since one side interval was in the wire coming from the negative, and the other in that from the positive coating.

whirl is one of these. Another is the perforating of paper or cardboard by passing the electric spark through them, and a remarkable fact is that the edges of the paper round the hole will be found turned up on *both sides* instead of only on one, as in an ordinary perforation by burning. Formerly this was supposed to be a proof of the double current, it is now, however, rather considered to be a consequence of the mechanical effects of the current spreading equally in all directions. Lichtenburg's dust figures also show the mechanical power of electricity. They are made by means of two powders (often vermilion and sulphur), being shaken together in a muslin bag and then sifted on to a cake of resin. The friction causes the powder particles to become electrified, the vermilion positively and the sulphur negatively, consequently the negative parts of the resin attract the vermilion, and the positive the sulphur, so that the two powders arrange themselves in distinct and quite different shapes.¹

Of other effects of discharge, that on the magnetic needle must be mentioned. It is deflected from its true position when close to the place of discharge, and during violent thunderstorms ships' compasses

¹ Another way of making these figures is by tracing a pattern on the resin with the knob of a charged Leyden jar, and then sifting the powder over it.

have often been rendered quite useless, owing to the influence of the lightning on them. A steel needle may be made into a permanent magnet by being placed within a wire spiral through which a discharge is passed. Discharge also produces considerable physiological disturbances, which are most strikingly illustrated by lightning, and will therefore again be referred to under the head of atmospheric electricity; but powerful electrical machines and Leyden jar batteries can produce effects quite as marked, and sometimes fatal where proper precaution is neglected. Even a single ordinary jar may give a very unpleasant shock, as Cuneus and many others have proved! The "return shock" experienced by persons standing at a little distance from an electrical machine which is being discharged, or from some object "struck" by lightning is due to induction. The effect of the charged conductor (whether a cloud or the prime conductor of a machine) is to induce a charge of opposite kind in all neighbouring objects. When it discharges, they follow its example, their charges being no longer bound, and the consequence to a living body is a "shock."

Lastly, a discharge passed through chemical compounds causes their decomposition, and its effect on the air, as we have already seen, is the production of ozone.

CHAPTER V

ATMOSPHERIC ELECTRICITY

Identity of lightning and electricity—Franklin's kite experiment—Its repetition by Romas—Danger of these experiments—Death of Richman—Existence of atmospheric electricity independently of thunderstorms—Results of modern observations—Daily variations—Annual variations—Electrified clouds—Signs of atmospheric electricity in dry cold weather—Ozone—Its importance to health—Not found in contaminated air—Same true of positive electricity—Ozone an active chemical agent—The Aurora Borealis—Frequent appearance in high latitudes—Description—Resemblance to discharge through rarefied gases—Probable origin—Effect on the magnetic needle—Improbability of its being attended by sound.

MANY early observers noticed the resemblance between the flash and crack of the electric spark, and those tremendous natural manifestations lightning and thunder. It was reserved for the great American philosopher, Benjamin Franklin, however, to establish their identity by actual experiment. Having observed that lightning usually strikes the most elevated objects, he resolved to erect a sort of sentry-box on some high

tower, from which a pointed and insulated rod could be raised, and thus enable him to make his observations. Before this could be accomplished, his fertile brain suggested another expedient to which resort could be had the first time a thundercloud approached, and which therefore he determined to adopt. This was to use a common kite, suitably prepared. He made one of silk, fastened an iron point to it, and furnished it with a string, the upper part of which was of ordinary twine, but the lower part of silk. At the junction of the two he attached a key. At the first sign of a thunderstorm he went out into the country accompanied by his son, and let fly the kite. At first, to Franklin's intense disappointment, no signs of electricity were obtained, but in a short time he noticed the loose fibres of the string begin to bristle, and holding his knuckle to the key, a bright spark passed between the two. Rain then fell, the string became wet, and its conducting powers consequently much better, and in a short time numerous large sparks were drawn from the key, proving beyond a doubt that Franklin's surmises were correct, and lightning and the electric spark identical. This celebrated experiment was made at Philadelphia in 1752.

In 1753 it was repeated on a very grand scale by the Frenchman Romas, and in presence of several

spectators, Romas himself receiving a very severe shock, which warned him to use a discharging rod instead of his knuckles to draw the sparks, the latter being so powerful that they appeared like flashes of fire a foot long, and were accompanied by a noise audible at 500 feet distance. At the commencement of this experiment no rain was falling; when it began to do so a great increase of electricity was perceptible, and Romas dared not draw sparks even by means of the discharging rod. Both he and the bystanders experienced the peculiar sensation, "as though a spider's web had been upon the face," which is sometimes felt near an electrical machine, and the explosions and flashes of fire were attended by the strong and characteristic smell accompanying a violent lightning discharge, and the working of electrical machines. This odour was described by nearly all early observers as "sulphurous," but in reality it more resembles that of phosphorus, and is now known to be due to the production of ozone.

It is evident that experiments of this description, unless conducted with the very greatest care, are in the highest degree dangerous, and before long a fatal accident checked the growing ardour of the scientific world for making them. On the 16th of August 1753 Professor Richman of St. Petersburg, while conducting experiments during a thunderstorm on an

insulated iron rod, projecting from the roof of his house and carried down into the room where he worked, was killed by a sudden flash of electric fire which darted from the rod with a loud report. So terrible a warning was not unheeded, and experiments on lightning became very rare; in fact, it may be said that since this period hardly any have been undertaken, though many facts and observations have been collected, and the rapid growth of electrical science has enabled practical men to grapple, to a very great extent successfully, with the problem of protection from injuries to life and property due to lightning.

Before entering upon the subject of thunderstorms, which are occasioned by an abnormal electrical condition of the atmosphere, it will be well to glance at what that condition is when no storms are in progress.

The discovery that electricity exists in the atmosphere quite independently of thunderstorms was an almost immediate consequence of Franklin's famous experiment with the kite. The Abbé Mazeas discovered in 1753 that signs of atmospheric electricity could be obtained in fine dry weather at all hours between sunrise and sunset; and Franklin himself attached a pointed iron rod to his house, which could be insulated when he chose, and to which he con-

nected a system of the electric chimes previously described. Whenever the conductor was affected by the neighbourhood of some charged cloud, the chimes began to ring, and Franklin's attention was drawn to the fact that a favourable time for his observations had arrived. His apparatus did not enable him to ascertain more than that ordinary clouds were sometimes positive and sometimes negative, more often the latter ; and no very great advance was made in the knowledge of atmospheric electricity till the electroscopes and electrometers of modern days were applied to this purpose. And even now but little has been positively ascertained on this subject. From observations made at various times in different places, and compared and verified by eminent men of science, the following facts have, however, been elicited. The potential of the air increases with increase of distance from the surface of the earth, which might be caused by the latter possessing a negative charge, but it is not known whether this is really the case. In fine calm weather the atmosphere is positive ;¹ in cloudy, rainy, and windy weather it is very often negative, but will sometimes

¹ The lower strata of the atmosphere are non-conducting when dry. It is at some distance above the surface of the earth that indications of positive electricity are obtained. According to some recent observations, earthquakes appear to occasion a negative electrification of the air.

change rapidly from one sign to the other. Clouds are always electrified, and often to a very high potential. Usually they are positive, but there are many exceptions. The electrical condition of the air is subject to daily and annual variations. Every twenty-four hours there is a decrease of electricity, beginning an hour or two after midnight and continuing till shortly before sunrise, when an increase commences and goes on until some hours after sunrise, when the first maximum is attained. The electrical condition of the air then remains stationary for a short time, after which another decrease sets in until some hours after noon, when a minimum is reached. Another short pause ensues, and then a second increase takes place, attaining its maximum some hours after sunset. Then occurs the second decrease, reaching its minimum about midnight. Many local causes, however, may modify the ordinary electrical condition of the air and its daily variations. Fogs are highly electric, and their presence always considerably raises the potential of the atmosphere. Snowstorms accompanied by high wind are sure to produce very strong indications of electricity, and this fact favours the idea, that one important source of atmospheric electricity may be the friction against each other and the earth of solid and liquid particles, brought about by the wind.

The annual variations of atmospheric electricity consist in a gradual increase beginning from May or June, and attaining a maximum in one of the winter months, varying with the locality in which the observations are made, and a gradual decrease commencing from the time of maximum, and continuing until a minimum is reached in the early summer. It is therefore during the winter months that the air is most highly electrified, a circumstance which may perhaps surprise those who are accustomed to think of thunderstorms as the only signs of atmospheric electricity, for these in our climate are far more common in summer than in winter. It is not, however, a uniformly high potential which occasions storms, but great differences of potential, and these occur in England more frequently in summer than in winter, owing to the larger amount of evaporation which is going on. Vapour in considerable quantities rises from the earth and sea, drawn up by the heat of the sun, and on reaching the higher and cooler layers of air, condenses. Now, evaporation has been proved by experiment to be always attended by a development of electricity; and the vapour particles are therefore all in an electrified condition. When they condense into a drop, their united electricity spreads itself (according to the laws of electrical equilibrium) over the surface of

the drop, which, however small it may be, is far more highly electrified than any one of the vapour particles which have gone to form it. These minute drops again coalesce into larger ones, with the result of a still further raising of potential, and a cloud which is formed of an incalculable number of such electrified drops attains a very high potential indeed, and becomes capable of exerting a strong inductive influence on neighbouring clouds and on the earth, and thus of giving rise to thunderstorms. Though atmospheric electricity is not indicated in this way during winter, or at any rate but rarely, it gives other less obtrusive signs of its presence. It is in the winter months that single well-isolated objects become most easily electrified; every one knows that the peculiar crackling of the hair when combed occurs almost invariably in dry frosty weather, and articles of clothing will also then frequently show signs of electrification. Rubbing the hand briskly against flannel or any woollen material, occasions a crackling noise accompanied in the dark by sparks; and brushing woollen garments will often cause them to become more dusty than before, owing to the friction electrifying them and making them attract small floating particles of matter. In New York, where very dry and intense cold is experienced in winter, these electrical effects are very marked;

the dryness of the air in dwelling-houses being increased by the method of warming, and the insulation of different objects by the thick woollen carpets used. It is stated that "if one move upon such a carpet with a sliding or scraping motion, and then present the knuckle to a metallic conductor, such as the handle of the door, an electric spark accompanied by a crackling noise will be perceived. If one goes in this way once or twice quickly along the carpet, the spark may be three-quarters of an inch long, very brilliant and accompanied by a tolerably loud noise."¹ In order to observe these phenomena well, the carpet should be entirely of wool and thick. The authority above quoted gives an amusing account of a visit to a lady in New York in a house where the conditions were particularly favourable. She drew brilliant sparks from the gas chandelier, a visitor advancing to shake hands with her, would receive a perceptible shock, and a spark would pass between herself and a lady friend bending to salute her.

The dry cold weather which is best adapted to the manifestation of these and kindred phenomena is considered particularly favourable to health; most persons then experiencing a feeling of much greater physical briskness and activity; and it does not seem improbable that this may be partly owing

¹ *The Thunderstorm*, p. 289.

to the more highly electrified state of the air. In any case, electricity must certainly be considered an important salubrious agent, for to it we apparently owe the existence of ozone, on the necessity of which modern sanitarians insist so strongly. As has already been stated, ozone is a modified and much more active form of oxygen. Its presence in large quantities (as during the working of an electrical machine), is made known by a strong and peculiar odour, but in thoroughly good and pure air there is always a small amount of ozone, and its absence is a sign that the atmosphere is in some way contaminated. It is not found in crowded rooms, in the confined courts of large cities, or in any place infected by the breath of men or animals. In the open squares of towns, on bridges and quays, and, in fact, wherever the air is easily renovated, and consequently pure, indications of ozone are readily obtained ; and it is worth while to observe that the same remarks apply to positive electricity, no traces of which are discoverable in close and confined quarters, or in crowded streets and dwellings. Besides its health-giving properties, ozone is an active chemical agent : it is a very rapid oxidiser, and possesses strong bleaching powers ; and organic substances exposed to its influence are corroded.

The last and most remarkable electrical pheno-

menon which will be mentioned in this chapter is the Aurora Borealis. All travellers in the far north are well acquainted with its changeful and exquisite light, so vivid as to clothe with glory the winter darkness of the Arctic Regions ; but even in England the Aurora is often visible, though far less brilliant than in higher latitudes. On one occasion, in early winter, the writer witnessed an exceptional display of its beauty. The whole northern horizon was covered with a deep rosy glow from which pale streamers extended far up into the heavens. Even this, however, was but a faint representation of the "northern lights" as they are known to the inhabitants of the Polar Regions, where they are described as often equal to the full moon in brilliancy, appearing in the most exquisite arches, continually melting one into the other to reappear in new and more beautiful forms, and varying in colour from a silvery whiteness to deep shades of orange and rose colour. The motion of the auroral streamers which start from the arches or glow is often exceedingly quick, and has gained for them among the inhabitants of the Shetland Isles the name of "the Merry Dancers." They change rapidly in form, die away in one place to break out in another, and are generally animated by a strong tremulous motion from end to end. This tremulous motion is like the flickering of the

light caused by passing an electric spark through an exhausted tube, and, in fact, the two phenomena resemble each other almost as closely as do the electric spark and a flash of lightning. It is therefore natural to refer their existence to a similar origin, and the Aurora Borealis is considered to be due to electric discharges taking place in high and therefore very rarefied strata of the atmosphere. The actual proof that its origin is electric lies, however, in the fact that the presence of the Aurora invariably affects the magnetic needle, making it deviate from its true position, and that often to a considerable extent, and over very large areas of the globe. The Aurora does not always appear in the due north, but frequently towards the east or west, and sometimes at both points simultaneously; neither is it always arched, but appears occasionally in strips, or in "undefined luminous clouds." Its position in the heavens is thought to affect the weather; thus after an eastern Aurora, dry cold is expected, whereas one in the west is supposed to cause storms and snow, and Auroræ in both quarters simultaneously, unsettled weather.¹

Early travellers frequently said that a peculiar "hissing, crackling, and rushing noise" accompanied very brilliant displays of the Aurora, but no such

¹ *The Thunderstorm*, p. 299.

sound has ever been heard by any scientifically trained observer, or indeed by any observer at all in modern times; and the fact of the Aurora taking place in very rarefied air, renders its being accompanied by sound highly improbable. The appearance of these heavenly fires, which is frequently such as to give the impression of their being carried along by an impetuous wind, irresistibly suggests the idea of a "rushing" sound as their fit accompaniment, and this may easily have given rise to the belief that it had been actually heard.¹

The Aurora is seen in the South Polar Regions as well as in the north, and is then called the "Aurora Australis;" but these southern lights, though still very beautiful, are not so striking and brilliant as the northern.

¹ M. Gaston Planté nevertheless credits the reality of this sound, and attributes it, as he does that which accompanies globular lightning, to the sudden vaporisation of liquid particles by the passage of the electric discharge (*Phénomènes électriques de l'Atmosphère*, p. 146).

CHAPTER VI

ATMOSPHERIC ELECTRICITY CONTINUED—

THUNDERSTORMS

Analogy between Leyden jar and conditions giving rise to thunderstorms—Reason of repeated discharge in the latter—Short duration of lightning—Brilliancy—Colour of lightning flashes—Shape—Forked lightning—Cause of ramification—Possibility of the light of one flash producing another—Bifurcation—Sheet lightning—Thunder—Globular lightning—Planté's experiments—His conclusions from them—Chemical effects of lightning—Heating effects—Fulgurites—Explosive effects—Probable cause—Examples—Length of lightning flashes—Altitude of thunderclouds—Magnetic effects of lightning.

It was stated in Chapter IV that the conditions giving rise to thunderstorms are the same as those of a charged Leyden jar. We may go a little further than this, however, and say that possibly the inhabitants of the earth live in a huge Leyden jar, which is usually but slightly charged, but may at almost any moment become electrified to a very high degree. The earth's surface, which there is reason to believe may be always faintly negative, would form one coating of

this jar, the clouds and upper strata of the atmosphere the other, and the air between would be the dielectric. Now if owing to rapid evaporation and condensation, or to other of the various causes which generate and increase atmospheric electricity, clouds form whose potential is very high, they act inductively on the surface of the earth and all objects which rise from it, and these become strongly charged in the opposite way, the air between the clouds and the earth being thrown into a state of strain exactly similar to that of the glass in a Leyden jar. By and by this strain becomes so great that the air gives way under it, a rent is made, a dazzling flash of lightning is seen, a loud roll of thunder heard, and a beginning of discharge is made ; but a beginning only, for as we well know by experience, thunder-clouds do not discharge themselves at once like Leyden jars, the lightning and thunder will often continue for hours with but little interval between the flashes, and no diminution in their brilliancy. The reason of this lies in the way in which clouds are formed of innumerable drops, each one electrified and each one insulated from its neighbour. Because of this, a cloud is electrified throughout its whole mass, and not only on its surface, therefore so soon as one surface discharge is over, more electricity replaces that which has been dispersed, and a similar

state of strain recurs, to be relieved by another discharge, rarely, however, following exactly the same path as its predecessor. Discharges take place between different clouds, as well as between clouds and the earth. In the former case there may be no danger to be apprehended, but in the latter very serious and alarming consequences often ensue, though the use of lightning-rods, imperfect as the latter may still be in some respects, has certainly diminished the number of accidents to life and property.

The two principal characteristics of lightning are its short duration and its extreme brilliancy. A flash of lightning is thought to last about one ten-thousandth part of a second. This fraction of time is so minute that it is difficult to form an idea of it, but a rough notion of the momentariness of lightning can be obtained, by observing that an object moving at however great a speed, the wheels of a carriage, or of a train, appear absolutely stationary when seen by it. Even a rifle ball would look as if poised motionless in mid air. One experiment which has been made proving this extremely short duration of lightning, is to observe during a flash a very rapidly rotating disc, painted in alternate black and white sectors, running from the centre to the edge like the spokes of a wheel. By daylight such a disc

appears gray while revolving, as its speed is so great as to allow no time for the eye to distinguish between the black and white, which are consequently mixed together and form gray. Seen by a lightning flash, however, the black and white sectors stand out clearly with gray ones between them, the fraction of space through which one sector is able to move while the flash lasts, being so small as to produce almost the same effect as though it were stationary. In order to produce exactly the same effect and have no gray at all, it would be necessary for the illumination to be really instantaneous, which is impossible.

One consequence of the short duration of lightning is an apparent diminution of its brilliancy. It has been proved that light cannot produce its full effect on the eye, unless it remains at least as long as one-tenth of a second. But lightning lasts only the ten-thousandth part of a second, and it follows from this that we see it one hundred thousand times less bright than it really is. When we recollect that even thus diminished its brilliancy is such as to cause temporary blindness if too closely watched, we may feel grateful that we cannot see it in its true vividness, for any human powers of vision would be too weak to bear such a sudden and overwhelming illumination.¹

¹ It should be stated, however, that there is some evidence, chiefly photographic, that lightning flashes may at any rate occa-

The colour of lightning varies according to the condition of the atmosphere. If the latter be saturated with moisture, red will probably be the predominating hue, because the intense heat developed by the passage of the flash decomposes and rarefies the air and the watery vapour it contains. If therefore the latter be abundant, rarefied hydrogen, which is red when an electric discharge passes through it, will give its hue to the lightning. If, on the contrary, the air be comparatively dry, or the quantity of electricity in play not very large, the colour of the flashes will be blue or bluish-violet, which is that of rarefied air during the passage of an electric discharge.¹

The shape of a flash of forked lightning varies according to its length, and the equality of resistance it encounters in its path from a cloud to the earth, or from one cloud to another. If the distance be short, and the air of a tolerably uniform density, the flash may be nearly or quite straight ; but if there is a long way to traverse, and the air is in different states of density at different points (as is almost invariably

sionally be of longer duration than is usually supposed, and the magnetising power of lightning also points to this conclusion. See the discussion on lightning-rods during the meeting of the British Association at Bath, 1888.—*Report of the British Association for 1888*, pp. 593, 598, 601.

¹ Planté, *Phénomènes électriques de l'Atmosphère*, pp. 34, 35.

the case during a thunderstorm), the flash is sure to pursue a very irregular and winding path, sometimes seeming to meander about in the air, sometimes even

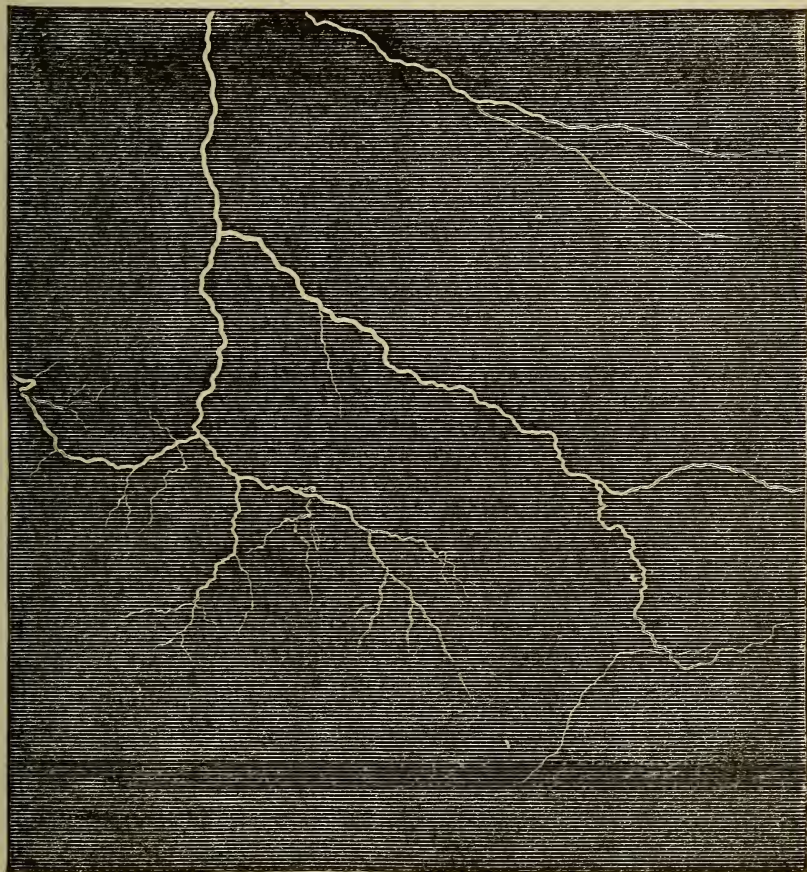


FIG. 7.—From a photograph taken in the early morning of 7th June 1889 at Peterborough by Mr. A. W. Nicholls.

making loops and knots in its progress (Fig. 9), and in all cases frequently giving out side flashes, as represented in Figs. 7 and 8.



FIG. 8.—From a photograph taken by Mr. C. A. E. Pollock at Corpus College, Cambridge, on the night of 6th June 1889.

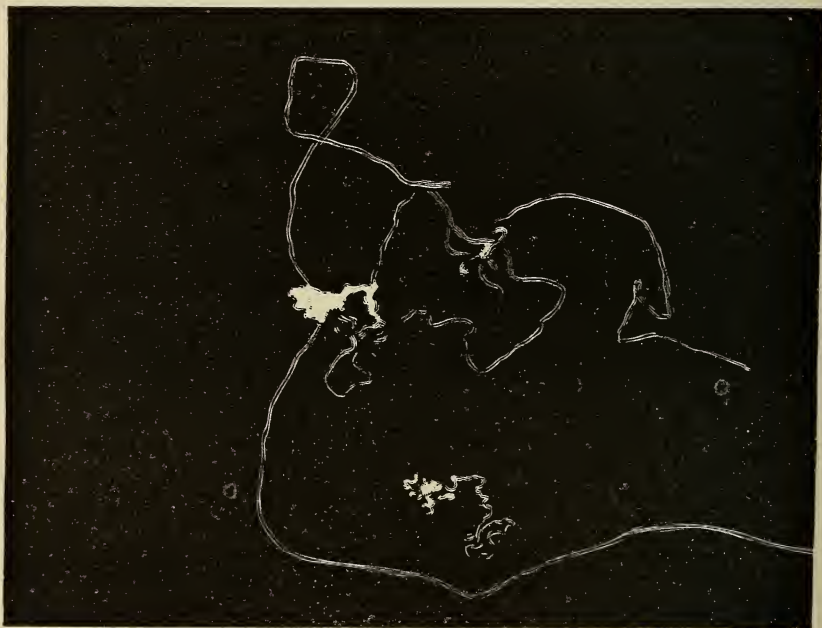


FIG. 9.—From a photograph by Mr. A. K. Baird taken at Edinburgh, on 6th June 1889, about 9 P.M.



FIG. 10.—From a photograph taken in the early morning of 7th June 1889 at Peterborough, by Mr. A. W. Nicholls.

The cause of the irregular path of a lightning flash lies in the tendency of electricity to take the path of least resistance; it would rather run round an obstacle, if possible, than overleap it, and a long electric spark will often exhibit on a small scale exactly the same peculiarities of shape as a flash of lightning, and for the same reason. The forking, or to speak more correctly, the branching of the lightning (for seen in a photograph one flash often seems to ramify into others, like the roots or branches of a tree, Fig. 7,) has a different cause. It is thought that one lightning flash gives rise to others following nearly, though not quite, the same direction as itself; and when we remember that the

cause of lightning is the breakdown of the air under the strain to which it is subjected, this hypothesis becomes exceedingly probable, for all round the path of the flash, and not only in it, this same strained condition obtains, so that the mere shock of the air giving way at one point, would seem to render its giving way at other neighbouring points, almost a matter of certainty.

There is another way in which one lightning flash may perhaps be the cause of others,—a way which is particularly interesting because it serves to show the exceedingly intimate connection between light and electricity. It is a curious and remarkable fact that if the light of an electric spark is made to fall on the space between two conductors, which are highly charged but just not able to spark into each other, they will at once do so, especially if the light fall on the conductors themselves,—showing that under certain conditions the mere effect of light is able to produce an electric discharge. Now, since lightning is in reality simply a very enormous electric spark, it is only reasonable to suppose that it will behave like one, and therefore that under some circumstances the *light* of one flash will cause another flash. The probable reason of this phenomenon can only be briefly alluded to, but it is of too great interest to be passed over entirely. It has already been stated

both that the discharge of a Leyden jar is often oscillatory and that it is the type of all discharge, including that of lightning. It follows then that lightning discharge may be oscillatory. Now in a medium able to transmit them oscillations or wave-movements spread, and with light and electricity the ether is the medium through which they spread, as air is the medium through which sound-waves spread. In the case of sound, it is well known that if two tuning-forks of the same pitch be placed near each other, on striking one the other will give out its note also; this is because the vibration of the first, communicated through the air to the second, sets up in that a similar vibration. It would seem that an electric spark or a flash of lightning caused by the light of another spark or flash must have an analogous origin. A vibration is set up by the first flash which is communicated through the ether to the point where the state of things is such that another similar vibration can be set up, and a second flash is the result. Such a combination of conditions may be rare, (it is not always that we find two tuning-forks near at hand able to be excited the one by the other,) but it is certainly possible, and its occurrence, if it could be proved, of the very highest interest.¹

¹ Professor Rowland appears to think that the "return shock" (which in the case of a lightning flash often takes place at a very

A single flash of lightning will sometimes divide when it strikes an object, and take two or even more different paths for the rest of its journey to the earth, working destruction in each, unless very efficient lightning conductors be provided. Some description of these and the injurious effects they are intended to guard against, will be given shortly. In the meanwhile mention must be made of the second kind of lightning flash, the *sheet*, and of a third, which is not a flash at all and is but seldom seen, viz. *globular lightning*.

Sheet lightning presents the appearance of a broad flash, emanating from the edge of the cloud, or occasionally from the centre, when the cloud looks as if it opened to allow of the exit of the electric fire. No object on the surface of the earth is ever struck by it; it is in fact a discharge between cloud and cloud, much of the nature of a brush discharge, and

considerable distance from the actual point of discharge,) may be explained on a similar principle. In a lecture given at New York before the American Institute of Electrical Engineers, he said, "If they (the oscillations) take place, we have a ready explanation of what is sometimes called a back stroke of lightning. That is, a man at the other end of the cloud a mile or more distant from the lightning stroke sometimes receives a shock, or a new lightning flash may form at that point and kill him. This may be caused, according to our present theory, by the arrival of waves of electrical disturbance, which might themselves cause a slight shock, or even overturn the equilibrium then existing, and cause a new electric discharge."

not a discharge between a cloud and the earth. Occasionally sheet lightning is seen on a clear sky and unattended by thunder, and it is then often called summer or heat lightning. This is no doubt the reflection of flashes from a storm below the horizon, and too distant to allow the sound of the thunder to reach the ear of the observer. The thunder itself, is supposed to be due to the sudden and violent expansion of the air caused by the enormous heat developed in the path of the lightning. The rolling sound is occasioned partly by echoes from the different surfaces of the clouds and from strata of air of unequal density, and partly by the great length which a lightning flash sometimes attains. The flash is practically simultaneous along its whole path, but since sound takes a very much longer time to travel than light, moving at the rate of only about 1100 feet a second, the noise of the thunder though started at the same time throughout the entire line of discharge, reaches the ear by degrees, the sound from the nearest point first and that from the points farther away afterwards, according to their distance.

Globular lightning, *i.e.* lightning having the appearance of an intensely brilliant luminous or fiery ball, was long held to be fabulous, and the accounts of it have certainly often been greatly and even ridiculously exaggerated. Nevertheless, there re-

mains now no manner of doubt that this phenomenon though rare compared to that of forked or sheet lightning does most unquestionably occur.¹ Persons trained to scientific observation have recorded its appearance, and their accounts tally in the main particulars with those of other observers. Globular lightning may either descend from the clouds² or ascend from the earth,³ or it may float along at a greater or less distance from the soil.⁴ Its movement is slow and its path often extremely capricious. Its duration varies from a few seconds to a minute or more. Its disappearance is sometimes noiseless and harmless, sometimes attended by a loud explo-

¹ The writer in the year 1870 herself witnessed an appearance of globular lightning. It occurred in Wiltshire during a heavy thunderstorm which, not being immediately overhead, allowed of a continued observation of the lightning flashes. These presented nothing specially remarkable. The storm was in the neighbourhood of the Westbury Downs, at some distance above which there was a thick, leaden canopy of cloud. Towards the end of the storm there fell from this cloud an egg-shaped luminous body which apparently dropped to some point on the hills, where it disappeared. Some seconds afterwards there ensued a long, heavy roll of thunder. As the hills are distant about three miles, as the crow flies, from the place where the writer was situated, this luminous globe would appear to have been of considerable size. Its brilliancy was apparently that of ordinary forked lightning observed from the same distance, but its motion very much slower, the globe remaining visible for two or three seconds. No rain was falling at the time.

² *Phénomènes électriques de l'Atmosphère*, p. 201 ff.

³ *Ibid.* p. 214 ff. Forked lightning also, though rarely, ascends.

⁴ *Ibid.* p. 47.

sion and disastrous effects. Some accounts have described these fiery balls entering the window of a house and going up the chimney. This is probable enough, as the column of hot air would make an excellent conducting path for the electric discharge. Owing to the same cause, no doubt, there have been accounts of similar visitors coming down the chimney, to the great consternation of the witnesses. Globular lightning has been observed in the centre of thick clouds during a thunderstorm, and passing between one cloud and another,¹ and also occasionally with a rotatory movement.²

Many of the phenomena of globular lightning have been artificially reproduced on a small scale by the late eminent French electrician, M. Gaston Planté, whose experiments were, however, conducted by the aid of current, not static electricity. He used powerful secondary batteries³ which give currents of a very high potential, and succeeded by their means in producing small and intensely brilliant globules of fire on the surface of water, on a sheet of mica placed between two conducting surfaces, and lastly in the air-space between two damp sheets of filtering paper.⁴ These luminous globules behaved

¹ *Phénomènes électriques de l'Atmosphère*, p. 207.

² *Ibid.* p. 202.

³ See Part III. chap. i. p. 148.

⁴ *Phénomènes électriques de l'Atmosphère*, chap. i.

in the same manner as globular lightning. They moved slowly, followed, in the second and third cases, very irregular paths, and their duration was considerable. M. Planté was led by his experiments to the conclusion that globular lightning must be produced by "dynamical" electricity (*i.e.* current electricity) of very high potential and in large quantities, and that the fiery globes themselves are formed of "rarefied incandescent air, and of the gases resulting from the decomposition of vapour of water also in a state of rarefaction and incandescence."¹ The brilliancy of these globes is due, according to M. Planté, to the quantity of electricity in play at the time of their appearance, and it is a fact that they are only observed during storms of exceptional severity. The rustling noise which often accompanies them he refers to the rapid vaporisation of liquid and solid particles in the path of the electric discharge, and the variation of colour to the same cause which produces it in ordinary lightning.²

Lightning produces chemical changes similar to, but on an enormously larger scale than those of an electric spark. It is often attended by a copious generation of ozone, to which fact may be referred the powerful odour often mentioned by persons who

¹ *Phénomènes électriques de l'Atmosphère*, pp. 29, 30.

² See p. 74.

have been near an object "struck" by lightning. It also decomposes the oxygen and nitrogen of the air in order to form nitric acid, strong traces of which are found in specimens of rain-water collected during thunderstorms, while at other times it is either entirely absent, or present in almost infinitesimal quantities. The heating effects of lightning are also very great; it fuses and even vaporises metals; but perhaps the most wonderful examples of its power in this way are the fulgurites or tubes of vitrified sand found in many places, and now known to owe their origin to lightning. Some remarkable tubes of this kind were found near Drigg in Cumberland in 1812, one of which was considerably more than thirty feet in length, and varying in diameter from an inch and a half, at the surface of the sandhill in which it was found, to half an inch at the bottom of the excavation made. Small branches, two or three inches long, and a quarter of an inch in diameter, protruded from the main stem. The outer surface of these tubes was rough and uneven, but the inner surface was formed of a "whitish or limpid vitrified matter, covered with a smooth glaze, and hard enough to scratch glass."¹ Similar tubes were found by Darwin in South America near the River Plata,² and attempts

¹ *The Thunderstorm*, p. 117.

² *Journal during the Voyage of the Beagle*, pp. 43, 44.

have been made with partial success to imitate them artificially, by means of passing a powerful electric discharge through various hard, powdered substances. The experiments succeeded with glass dust, a tube an inch long having been formed in this way, but failed with felspar and quartz, out of which lightning has nevertheless manufactured tubes thirty feet in length.

The most remarkable of all the effects due to lightning, however, are the extraordinary explosions it causes, and which have been attributed to the sudden vaporisation of any moisture contained in the solid materials, such as stone, wood, etc., through which the discharge is passing. The formidable expansive power of steam is well known, and we may therefore conceive that if all the moisture contained in a tree or in a mass of stone were suddenly turned into vapour, the pressure would be such as to burst everything before it.¹ Instances of explosive effects in buildings will be given hereafter. With regard to trees, it is stated that "on the 25th of May 1842, at the village of Adforton, near Ludlow, lightning struck a poplar-tree nearly forty-five feet high; it was shivered to pieces, and the ground for a hundred yards round it was thickly covered with splinters, from four to twelve inches long, many of

¹ Arago's theory as quoted in *The Thunderstorm*, p. 122.

which seemed to be entirely smashed. The body of the tree was divided into eight or ten large portions, which came away with the branches and fell wide of each other, but all on the south side.”¹ This is one example out of many equally remarkable.² Still more striking are some of the explosive accidents due to lightning on board ship. On 19th September 1812 H.M.S. *Sultan* (of seventy-four guns) was struck by lightning off the coast of Sardinia, “the highest spar or top-gallant and royal mast was fairly shaken in pieces; the next, or topmast, seventy feet long, was burst into shreds like a bundle of laths, and stood gaping open in the upper end; it remained in this condition for some minutes, and then fell with a terrific crash. So complete was the destruction, that the decks of the ship were filled with the chips of wreck of more than three tons of wood. The next, or lower mast, weighing eighteen tons, was struck through to the very centre; and the lightning made

¹ *The Thunderstorm*, p. 127.

² A very similar but not quite so destructive flash is mentioned in *The Electrician* for 27th June of the present year. During a storm at Playford in Suffolk, “a poplar tree, about 300 yards away from the church, was struck by lightning, and the bark was completely stripped away from top to bottom, the southern half of the body being riven into matchwood. One piece, $5\frac{1}{2}$ lbs. in weight, was picked up 126 yards away from the tree, and the débris covered about two acres of land. The discharge left the tree at the foot, following the direction of a fence for about 15 or 20 feet, threw up a sod about a foot square, and went to earth.”

one or two holes in it sufficiently large for a boy to creep into. The chips which were torn out were thrown about the deck. It was with difficulty prevented from falling till the ship got into port, when the mast in its ruined state was taken out. On removing the mouldings and fishes it literally fell to pieces.”¹

The length of lightning flashes has been very variously computed, some authorities considering that it may be a mile or even more in length, others that it can never exceed 500 or 700 feet.² Probably the truth lies somewhere between these two extremes. At any rate it seems certain that thunderclouds never attain very high altitudes, probably not over 7000 feet above the sea-level. On high mountains thunderclouds are seen below the observer; and thus it would appear that while auroræ are chiefly, if not entirely, confined to the upper strata of the atmosphere, thunderstorms take place in the lower.

The magnetising power of lightning must not be left unmentioned. After thunderstorms at sea the action of the ship's compass has often been impaired. Occasionally the polarity of the needle is actually reversed, and often pieces of iron and steel become

¹ *The Thunderstorm*, p. 130.

² See discussion on lightning-rods at the meeting of the British Association, 1888.

magnetic through the passage of lightning. Watchsprings have frequently suffered in this way, and after the remarkable storm during which the church of St. George's, Leicester, was partially destroyed, described in the ensuing chapter, the iron cramps in the steeple and other masses of metal were found to be highly magnetised. These magnetising effects are taken to indicate that the duration of lightning is, at any rate occasionally, considerably longer than is usually supposed, as magnetisation is not momentary, but takes an appreciable time to accomplish.

Thunderstorms are not the only occasions of the manifestation of lightning. Violent volcanic eruptions are always accompanied by this, and sometimes by other electrical phenomena. Lightning seems to have been a specially-marked feature of the terrible Krakatoa convulsion, nearly all eye-witnesses of the eruption laying stress upon this, as greatly adding to the horror and magnificence of the spectacle. Thus Captain Woolridge of the *Sir R. Sale*, viewing the volcano from the N.E. at sunset on Sunday evening 26th May, describes the sky as presenting "a most terrible appearance, the dense mass of clouds being covered with a murky tinge with fierce flashes of lightning. At 7 P.M., when the dense vapour and dust clouds rendered it intensely dark, the whole scene was lighted up from time to time by the

electrical discharges, and at one time the cloud above the mountain presented the appearance of an immense pine-tree, with the stem and branches formed with volcanic lightning.”¹ The same observer, at a distance of forty miles, speaks of the great vapour cloud looking like “an immense wall, with bursts of forked lightning, at times like huge serpents, rushing through the air.” Another observer, whose vessel was situated about forty or fifty English miles N.W. of the volcano, records that “lightning struck the mainmast conductor five or six times,” and also that “the mud rain covering the masts, rigging, and decks was phosphorescent; the rigging presenting the appearance of St. Elmo’s fire.”

“This abundant generation of atmospheric electricity,” writes Professor Judd, “is a familiar phenomenon in all volcanic eruptions on a grand scale. Steam jets rushing through the orifices of the earth’s crust constitute an enormous hydro-electric engine; and the friction of ejected materials striking against one another in their ascent and descent also does much in the way of generating electricity.”²

¹ *Official Report of the Royal Society on the Eruption of Krakatoa*, p. 19.

² *Ibid.* p. 21.

CHAPTER VII

ATMOSPHERIC ELECTRICITY—*continued*

DANGERS TO BE APPREHENDED FROM LIGHTNING— MODES OF PROTECTION

Danger to life and property from lightning—Instances of loss of animal life—Death not inevitable from a “stroke” of lightning—Persons struck do not see the flash—Instance—Globular lightning is seen—Case of Mr. Pitcairn—Injury to buildings—Account of the partial destruction of St. George’s Church, Leicester—Dangers formerly encountered at sea during thunderstorms—Examples—Explosion of gunpowder magazines by lightning—Earliest lightning conductors—Their inefficiency—System of protection devised by Sir W. Snow Harris—Directions concerning lightning-rods—Modern modifications—Real use of lightning-rods—Perfect system of protection not yet attained—Necessity of employing experienced electricians to erect lightning-rods—Protection of individuals from lightning—Metal does not “attract” lightning—Theory of an “area of protection” exploded—The most elevated objects not always those struck—Reason.

THE dangers to be apprehended from lightning are, in the case of property, destruction by fire, or by the extraordinary explosive powers sometimes mani-

fested ; and in the case of man and the lower animals, severe injury or death, owing to the shock to the nervous system,¹ caused by the passage through a living body, of electricity in such large quantities and at such high potential. Timid persons are often ridiculed for the terror they show during thunderstorms. There is, however, something to be said in their defence, for though all storms are not dangerous, there is no doubt that some are so in a high degree, and moreover the disturbed electrical condition of the atmosphere before and during a heavy storm, is of itself sufficient to induce great nervous discomfort in sensitive organisations. Accidents due to lightning are now made so public, owing to the newspapers which flood the civilised world, that they perhaps appear more frequent than they really are ; but it is only necessary to remember the large number of thunderstorms which annually take place in the United Kingdom, and the small average of deaths either of men or animals occasioned by them, to feel reassured on this point. Before the introduction and better understanding of lightning-rods, indeed, high isolated

¹ This was until recently the reason assigned for death from lightning, or any powerful electric "shock." It appears, however, according to the latest investigations, that some direct effect is produced upon the heart, and that is most likely the immediate cause of death.

buildings, particularly churches, were only too often "struck," and ships also suffered terribly, but in our days such occurrences are comparatively rare, and it is to be hoped that with the further advance of electrical knowledge they will cease altogether.

Before entering on the subject of protection from lightning, it may be interesting to give a few examples of the terrible destruction it may work. First with regard to animal life. In 1858 twenty-five sheep were killed during a thunderstorm near Abingdon.¹ In the same year at Sacco in Italy, on the 17th of August, 120 sheep out of a flock of 140 were killed by lightning. The shepherd and the shepherd's boy were not injured, though the latter was carrying a kid in his arms which was killed.² This remarkable escape of human beings, when animals close by them are struck, is not unusual, and would seem to point to the conclusion that the lower animals are more susceptible than man to injuries from lightning. In some instances this could be accounted for by the greater propensity of animals to huddle together in groups, especially when terror-stricken. During thunderstorms such a tendency is dangerous, because the column of heated air rising

¹ *The Thunderstorm*, p. 163.

² *Ibid.* p. 163.

from their bodies offers a good conducting path to the electric discharge. No such cause, however, could have accounted for the death of the kid in the shepherd-boy's arms, and the escape of the boy himself. When human beings are struck and recover, (for to be struck by lightning by no means necessarily entails death,) they invariably say they did not see the flash which rendered them unconscious. Many instances of this are cited in *The Thunderstorm*, to which work frequent reference has already been made. A relative of the present writer, who was struck by a flash of lightning during a violent thunderstorm in Yorkshire in 1886, saw nothing, neither did his wife, who was close to him and suffered, though slightly in comparison, from the effects of the same flash. More curiously, the woman in whose farmhouse they had taken temporary refuge, and who was in another room, saw no flash either at this moment, but heard a sudden sharp explosion which she took for the report of a gun, and rushed in a state of great anger to demand an explanation from her guests, when, to her astonishment, she found one of them in an unconscious and apparently dying state. A short time sufficed to restore his senses, and no other injury was sustained, beyond a shock to the nervous system, which for a time affected the general health and spirits, but not in any serious or

incapacitating manner.¹ Globular lightning, whose movements are so much slower, is not thus invisible to those whom it injures. M. Planté cites an instance of a ball of fire the size of a fist, which, during a violent thunderstorm, appeared to two clergymen, Messrs. Wainhouse and Pitcairn, who were together in a room in the rectory of Steeple-Ashton, Wiltshire. It seemed to be one foot distant from them, and about the height of a man from the ground, and was surrounded by a dark smoke. Its explosion was attended by a noise comparable to the firing of several cannons and a strong "sulphurous" smell filled the house immediately afterwards. Mr. Pitcairn was dangerously wounded.²

With regard to buildings, churches and any high

¹ One of the curious tree-like marks which have often been noticed on the bodies of persons struck by lightning, was produced in this instance, and remained for a considerable time. It extended over the lower ribs on the right side, and resembled the trunks of two trees close together, with branches ramifying from them. The sufferer on this occasion also said that though he did not see the lightning, he heard the thunder; in fact, it was the last thing he remembered before losing consciousness.

² *Phénomènes électriques de l'Atmosphère*, p. 221. In a previous portion of this work M. Planté justly remarks "that it is not a small mass of air rarefied and rendered luminous by the passage of an electric current which could thus explode with the noise of thunder and resolve itself into 'strokes' of lightning. The source of this final phenomenon is in the reservoir of electricity contained in the thundercloud, which discharges itself at the point where the first escape began in the form of a ball of fire," p. 50.

or isolated erections are most exposed to danger from lightning. Mr. Tomlinson gives a formidable list of damages in *The Thunderstorm*, occurring between the years 1822 and 1858, in which no fewer than thirty-three churches are included, and enters into many interesting details with regard to several of them. The most striking account is that of the injuries sustained by St. George's Church, Leicester, on 1st August 1846, during a storm of quite exceptional violence and duration, and in which the phenomenon of globular lightning repeatedly presented itself. The storm had already been raging for hours accompanied by torrents of rain, when "at five minutes past eight, after one or two peals of unusual distinctness, the Church of St. George was struck with a report resembling the discharge of cannon, and with a concussion of the air which shook the neighbouring houses, and extinguished a lamp burning at the entrance of the newsroom, many hundred feet distant. . . . Two of the spectators of this awful event were Captain Jackson and the Rev. R. Burnaby, rector of the parish, who both described the flash as a vivid stream of light, followed by a red and globular mass of fire, and darting obliquely from the north-west with immense velocity against the upper part of the spire. For the distance of 40 feet on the eastern side, and nearly 70 on the west, the

massive stonework of the spire was instantly rent asunder and laid in ruins. Large blocks of stone were hurled in all directions, broken into small fragments, and in some cases, as there is every reason to believe, reduced to powder. One fragment of considerable size was hurled against the window of a house 300 feet distant, shattering to pieces the woodwork, as well as fourteen out of the sixteen panes of glass. . . . It has been computed that a hundred tons of stone were on this occasion blown to a distance of 30 feet in three seconds. In addition to the shivering of the spire, the pinnacles at the angles of the tower were all more or less damaged, the flying buttresses cracked through and violently shaken, many of the open battlements at the base of the spire knocked away, the roof of the church completely riddled, the roofs of the side entrances destroyed, and the stone staircases of the gallery shattered. The top of the spire, when left without support beneath, fell perpendicularly downwards inside the steeple, causing much devastation in its descent.”¹

The scene of this fearful accident² was afterwards

¹ *The Thunderstorm*, p. 153 ff.

² One almost equally severe appears to have occurred at Louvain on 8th April of the present year 1890. The cathedral was struck by lightning. “One of the turrets was completely destroyed, and the top, weighing about four tons, was projected a distance of twenty-

minutely examined, when it became evident that the formidable explosions which worked the destruction, were caused by the electric discharge on its road to the earth, bursting its way from one good conducting point to another through masses of badly conducting material. Thus we are told that "after traversing the vane and spindle, and the terminating iron supports, the only path left for the fluid was through a series of iron cramps, *separated by means of sandstone*; and here it was that the explosion commenced,—the stone being torn and hurled aside as it came in the path of the lightning to the lowest lead lights of the spire."¹

In this accident, terrible as it was, no life was sacrificed, but M. Planté cites an account of a violent storm which took place on the 27th of July 1769, during which several hundred persons being congregated in a large public hall suddenly saw a fiery globe the size of a large cannon ball appear through an opening in the roof. All the lights immediately went out, and more than seventy-six persons were killed or wounded.²

two yards, demolishing a house, while blocks of stones weighing from two to three tons were hurled a distance of nearly seventy yards, damaging the houses in the neighbourhood."—*The Electrician* for 6th June 1890, p. 109.

¹ *The Thunderstorm*, p. 156. Apparently this church was unprotected by any lightning conductors whatever.

² *Phénomènes électriques de l'Atmosphère*, p. 222.

However fearful the destruction worked by lightning inland may sometimes have been, ships were formerly exposed to a far greater degree of danger from this source. Isolated objects on the vast plain of the ocean, it was almost impossible that during thunderstorms, they could escape being made part of the path of an electric discharge between the clouds and the sea, and the wonder is rather that so many escaped, than that so many were "struck." Nevertheless, the destruction both of life and property before Sir William Snow Harris devised an efficient system of protection, was truly appalling. The accidents to H.M. ships alone between the years 1790 and 1840 numbered 280, some exceedingly serious, and the loss of life was proportionately great, 100 seamen having been killed, and 250 dangerously injured, while the monetary loss to the country was reckoned at £150,000.¹ Space forbids the citation of more than one instance, that of the *Repulse* a 74-gun ship. On the 13th of April 1810, the *Repulse* being off the coast of Spain, was overtaken by "a heavy squall of wind, with rain, thunder, and lightning, at which time the people were employed in getting down their washed clothes which hung from the rigging, when the ship was struck by two vivid flashes of lightning which

¹ *The Thunderstorm*, p. 171.

shivered the maintop-gallant mast, and severely damaged the mainmast. Seven men were killed on the spot, three others only survived a few days, and ten were maimed for life. After the second discharge the rain fell in torrents; the ship was more completely crippled than if she had been in action, and the squadron then engaged on a critical service lost for a time one of its fastest and best ships.”¹

More terrible yet is the description of accidents which occur when lightning sets a ship on fire. Fearful stories of suffering and privation have thus been added to the roll of disasters at sea. Amongst others the case of the *Tanjore*, a ship belonging to the East India Company is cited by Mr. Tomlinson. In May 1820 she was struck by lightning forty miles off the coast of Ceylon, two men were instantly killed, and many others rendered insensible; the cargo, which was partly of brandy, caught fire, and burned so fiercely that the crew and passengers had to hurry into the boats without waiting even to take food and water. Fortunately a few hours afterwards they met with a native vessel and so were rescued.²

Many instances have occurred of powder magazines being struck and exploded by lightning. “In 1855, on the 7th of October, about 2 P.M., a firework manufactory in Green Street, Liverpool, was struck

¹ *The Thunderstorm*, p. 172.

² *Ibid.* p. 182.

by lightning and blown up; the factory and the adjoining houses were destroyed, and many persons severely injured. . . . On the 10th of August 1857, about midnight, lightning fell on the magazine of Joudpore, in the Bombay Presidency, whereby some thousands of maunds of gunpowder were blown up. Five hundred houses were destroyed, and nearly one thousand persons are reported to have been killed.”¹

Enough examples have now been quoted to show the need of protection from lightning, and it is time to turn our attention to the means employed for attaining this end. Lightning conductors were an almost immediate consequence of Franklin’s famous experiment in 1752 (described on p. 58 of the present work), and only ten years later the first erected in England was put up by Dr. Watson at Paynsted. It is amusing to think that so little was the principle of their action understood, that during the War of Independence an animated discussion was carried on between the supporters of pointed lightning-rods and those who recommended rounded tops. The matter was made a political question, the pointed rods being in favour with Franklin and the Revolutionary party, and the blunt with “loyal subjects and good citizens;”² neither side considering the scien-

¹ *The Thunderstorm*, p. 169.

² *Ibid.* p. 223, note.

tific and practical question as to which was in reality the best protector worth attending to ! As a matter of fact, the pointed rods were of course preferable, points contributing to a silent and noiseless discharge, and round tops, on the contrary, being likely to cause an explosive discharge between the conductor and the cloud. In these early days, however, many other important matters besides that of points, were but ill understood. One lightning-rod stuck up anywhere, perhaps insulated at the bottom, instead of having a good earth connection, or run into a small stone tank of water, or into any other equally impossible place according to the better instructed ideas of the present day, was deemed sufficient. Ships also were provided with a chain conductor of very small dimensions, stowed away in a box, and taken out to be suspended from the masts if occasion required ! It is not surprising that such protection as this was found terribly inadequate, and that great danger was incurred by the sailors, through having to place these conductors in position during a storm. To Sir William Snow Harris belongs the honour of having first devised a really adequate system of protection both for buildings and ships. He insisted upon an unbroken line of metallic connection between every part of the building or vessel and the lightning-rods as indispensable. Isolated masses of metal

forming an integral part of any erection are fraught with danger, and exceedingly likely to cause such destructive explosions as those which occurred in the case of St. George's Church, Leicester, cited above,—for the lightning in leaping from one conducting point to another will shatter the badly-conducting substances obstructing its path. The upright rod or rods should be armed with one or more points, and should project above those portions of the building to which they are attached. They should also have a thoroughly good earth connection, *i.e.* the earth about them should be kept damp, and they should not be buried in charcoal, or beds of stone or rubble, nor led into enclosed tanks.¹ Running water on the contrary is excellent, as it affords a thoroughly good conducting channel for the electric discharge.

Lightning-rods should also have a good extent of surface, but they need not, as was formerly thought, be solid. Hollow rods are quite as good, and flat ribbons, or a bundle of separate strands of thickish wire, better still. The solid rods were used under the idea that they offered a greater amount of conducting material to the passage of the electric discharge, because currents of electricity (and a discharge is a momentary current,) penetrate the substance of

¹ It is specially recommended also that they should be buried deeply in the earth, not too near the surface.

conductors, and do not remain on the surface like static charges; but this only holds good of steady currents, not of sudden rushes of electricity like the discharge of a Leyden jar and lightning. In these cases the velocity is so great and the duration so short, that the electricity scarcely penetrates below the surface, and therefore the important matter is that the latter should be of sufficient extent, not that the conductor should be solid. A modification has also arisen in the views held as to the best metal to employ in the construction of lightning-rods. Until recently, copper was recommended by all electricians on account of its high conducting power, but it appears now that for this very reason it may be less suitable than iron, because, as Dr. Oliver Lodge stated in a lecture delivered before the Society of Arts on 17th March 1888, "If a great weight or a large reservoir of water were propped up above one's house, one would not say that, the safe thing being to get it down as quickly as possible, it was advisable to break away the props, or to blow the bottom out of the reservoir; no, one would prefer to let it slide slowly and gradually down a well-resisting channel, so as to disperse the energy gradually."

These words "to disperse the energy gradually" recall a consideration of the highest importance which must never be lost sight of in any system of

protection from lightning. The question at issue is not only—or even mainly—how to conduct a certain quantity of electricity safely and quietly into the earth, but how to dispose of the enormous energy developed by lightning which can neither be ignored nor conjured out of existence. Therefore a certain amount of resistance may be a good thing as affording work to do to overcome it, but it need hardly be said that it should never be sufficient to occasion great heating, as that at once entails the danger of fire, or the collapse of the conductor through fusion, either throughout its length, or at special points, such as the joints, where increase of resistance is encountered.

Even with every precaution taken, and a system of protection from lightning adopted in accordance with the best practical electrical experience of the day, absolute safety cannot be guaranteed, as was abundantly proved by the Hotel de Ville at Brussels, which is protected by a most elaborate and carefully-carried-out system of lightning conductors, having been struck by lightning, and a portion set on fire in the month of June 1888. But little damage was done, as the fire was almost immediately extinguished. Nevertheless the case is a most important and instructive one, showing as it does that protection from lightning, though vastly improved, is not even yet perfectly understood. One of

our leading electricians distinguishes between two main cases of lightning flash, the one caused by a steadily-increasing strain between a cloud and the earth, so that the path of the flash is inductively prepared beforehand, the other by a sudden rise of potential in a cloud, between which and the earth no strain previously existed, by the discharge of another cloud into it, so that an "impulsive rush" of electricity takes place to the earth without any previous preparation. He considers that in the first of these cases, a system of protection carried out according to present ideas would be efficient, but not in the second case, and his conclusions are based upon a number of interesting and highly instructive original experiments.¹

The foregoing remarks, though giving the merest outline of the subject, may nevertheless enable the general reader to understand something of its importance, and will at any rate serve to show him that the protection of a building from lightning cannot possibly be properly accomplished by any but practical electricians. A village workman must not be depended on for the erection of lightning-rods.

¹ See Mann Lectures before the Society of Arts by Dr. Oliver Lodge, F.R.S., in March 1888; also a paper by the same author on "Lightning, Lightning Conductors, and Lightning Protectors," read before the Institution of Electrical Engineers in April 1889, reported in *The Electrician* of 3d May 1889.

It may perhaps be of interest to mention that in the case of gunpowder magazines and other stores of explosive material, high pointed conductors are not recommended. It must always be remembered that owing to the facilities they offer, they are likely, if present in sufficient numbers and at a sufficient altitude, to determine a discharge, which might not otherwise take place, between a cloud and the earth, and though in ordinary cases this would not be a source of danger, it certainly would where gunpowder or other explosive substances are concerned, as the smallest side spark (such as frequently takes place from lightning-rods to other conductors in close proximity,) might cause a terrible accident. A network of iron entirely covering the edifice, or better still, making the erection itself of iron, is far preferable in such cases.¹

¹ Telegraphic and telephonic instruments and stations require special protection from lightning, and the guards with which they are provided, are almost always constructed on the principle that owing to the "impedance" offered by good conductors to a sudden flash (due to the oscillatory nature of the latter), it would rather jump over a short air-space than follow a length of wire. Double combs are used as protectors in telephone exchanges; a pair of plates separated by a very short space in telegraphic offices. These do not always prove efficient, however, and Dr. Oliver Lodge has devised a new lightning guard, for which he claims almost absolute perfection, and whose principle, in his own words, consists in taking "the overflow from one protector and giving it the chance of another; then taking the overflow from this and offering it another air-gap, and so on till nothing is left; at the same time

With respect to the protection of individuals from lightning, a few plain directions may be given. It is a well-known source of danger to stand close under trees or under any high and isolated object. Detached pieces of metal worn about the person should also be avoided, as well as standing near a fireplace if there is a fire burning. It is of no use to cover oneself with silk garments, or in fact to attempt insulation in any way, as this only increases danger. On the other hand, the rather impossible protection of a suit of armour would render its wearer perfectly safe so long as the joints did not become overheated, which might perhaps occur if the armour were actually struck. Such a defence, however, though excellent for the owner, would be exceedingly dangerous to his friends, for to touch it during the progress of a storm would ensure a violent, possibly fatal shock; and the same remark applies to iron network over houses and other erections. The building thus enclosed and all its inmates would be perfectly safe, but any one approaching it from the outside during a storm, and laying his hand upon the metal, would certainly rue the consequences.

diminishing the overflow from each protector as much as possible by the use of self-induction coils, which impede the violently varying or alternating rushes by their electro-magnetic inertia."—Quoted from a paper read before the Institution of Electrical Engineers on 24th April 1890, published in *The Electrician* for 23d May.

It must not be supposed, however, that there is anything in metal which attracts lightning. Such is not the case. On account of its high conducting power, it offers an easy path to the electric discharge, of which the latter will, if possible, avail itself ; but it will not go out of its way to pick out a lightning-rod, or any other metallic conductor. Instances have occurred of lightning striking buildings in close proximity to lightning-rods, erected under the idea that they would afford an " area of protection," within the limits of which nothing but themselves could be struck. This erroneous theory of an " area of protection " is fast dying out, as also that of the most elevated objects being always the ones struck. Very many instances are on record of houses in the immediate neighbourhood of tall trees suffering from lightning, while the trees themselves escaped ; and this, though apparently surprising at first, ceases to be so when we remember, that the state of strain to which all the phenomena of discharge are due, does not exist primarily between a cloud and the lightning-rod, tree, or steeple, or whatever the elevated object may be, but between the cloud and the whole of that portion of the earth's surface lying beneath it ; therefore all that these isolated and, in comparison to the extent of surface, small elevations can do, if they are good conductors, is to protect themselves from danger

by rendering that part of the discharge which is taking place between them and the cloud harmless. They cannot do more than this, and hence the paramount importance of a metallic connection between every part of the building to be protected and its lightning-rods. During the discussion on lightning-rods which took place between Sections A and G, at the meeting of the British Association in Bath 1888, a most remarkable photograph of a flash which occurred during a storm in America was shown. It can only be described by saying that the sky seemed to be literally pouring down the electric fire on every side, and the remark was justly made by its exhibitor,¹ "Where in such a case could the 'area of protection' be?" The only real safety would lie in the whole surface upon which this enormous quantity of electricity was descending being of good conducting matter; and in the presence of such tremendous manifestations of natural energy as this, we can but feel that though it behoves us to take every precaution which the most advanced Science recommends, our preservation depends on a Higher Power and a vaster Knowledge than any which our resources can command.

¹ The Hon. Ralph Abercrombie, F.R.S.

PART II

MAGNETISM

CHAPTER I

GENERAL PROPERTIES OF MAGNETS

Ancient knowledge of natural magnets—Lodestone an ore of iron—Made useful in navigation in the twelfth century—Gilbert's discovery of magnetic poles—Attraction between unlike and repulsion between like magnetic poles—The earth a magnet—Naming of the poles—Magnetic substances—Dia-magnetic substances—Action and reaction between magnets and magnetic substances equal—Similarities and dissimilarities between electric and magnetic induction—Magnetic induction cannot take place across magnetic substances—Acts across a vacuum—Various ways of making magnets—Consequent poles—Bar and horse-shoe magnets—Magnetic shell—Strength and lifting-power of magnet—Causes of loss of magnetisation—Subdivision of magnets—Molecular theory of magnetism.

NATURAL magnets were known from very ancient times, and their name is derived from Magnesia, in Asia Minor, where many of the hard black stones possessing the property of attracting iron and steel

were found. The English name of lodestone means simply leading stone. It is an ore of iron called by mineralogists *Magnetite*, and exists in large quantities in Sweden, Spain, and various other countries, though it by no means always possesses magnetic properties, being often found entirely destitute of them, nor is it known by what means they are acquired by those specimens of the ore which exhibit them. About the twelfth century it became known in Europe that lodestones, whose power of attracting iron was already attributed to magic, possessed another yet more marvellous peculiarity, viz. that of setting themselves always in a north and south direction when freely suspended. This property was made useful in navigation ; and in fact the name lodestone is derived from the fact of the magnet stones being able to act as mariners' guides. The first artificial magnets were made by rubbing iron or steel with lodestone, when it was found that the latter imparted its magnetic properties to these substances,—the iron, however, only retaining its magnetism for a very short time, whereas the steel, though not able to be so powerfully magnetised as iron, did not again lose the properties it had acquired, but became a permanent magnet. Other ways of making artificial magnets, which will be mentioned in due course are now known and extensively used.

Dr. Gilbert, whose electrical discoveries have already been mentioned, made many of equal importance respecting magnets, and in his work *De Magnete* described a number of elementary facts regarding them. He was the first to notice that the attractive power appears to reside at the two ends of a magnet, called always its *poles*.¹ This fact can easily be proved by placing an ordinary bar magnet among a number of iron filings, which will be seen to arrange themselves in thick tufts round the poles, thinning as the centre is approached, while at the actual centre there are none. This non-attractive part of the magnet Gilbert named the *equator*, and the imaginary line joining the poles, the *axis*.

It has already been mentioned that a freely-suspended magnet sets itself in a particular direction with regard to the earth, viz. with one pole pointing nearly north, and the other nearly south; moreover, it is always the *same* pole which points in the *same* direction, for if a magnet be turned by any means out of its natural position with regard to the earth, it will return to it again, the moment the constraining force ceases, the pole which was before pointing north resuming the same direction. Let it now be

¹ It is only in a long thin bar magnet that the poles are actually situated at the extreme ends, however. In thicker magnets they lie slightly nearer the centre.

supposed that there are two magnets, the north-seeking poles of which have both been marked. One of these magnets is freely suspended (or balanced upon a pivot, which comes to the same thing), the other being held in the hand. The free magnet will of course be turned into its usual north and south direction, and this being so, let its north-seeking pole be approached to the north-seeking pole of the second magnet, when it will be seen that the former is instantly turned away from the latter, thus showing that *two north-seeking poles repel each other*.

Let us now vary the experiment by approaching the south-seeking pole of the magnet held in the hand to the north-seeking pole of the free magnet. We shall find that the latter will turn *towards* the south-seeking pole, and if near enough, will rush into contact with it, thus remaining till the two are separated by force, showing that a *north-seeking and a south seeking pole attract each other*.

It would appear therefore, that as there are two kinds of electricity, positive and negative, so there are two kinds of magnetism, north-seeking and south-seeking. Moreover, since it is evident from the position taken up by a magnet with regard to the earth that the north part of the latter attracts one pole of the magnet and the south part the other, and

since only magnets have this power of attraction and repulsion over other magnets, we are driven to the conclusion that the earth itself must be a magnet obeying the invariable law that *like poles repel, and unlike poles attract each other*, and that this is the reason of the north and south direction taken up by a freely-suspended magnet, whose north-seeking pole points to the south magnetic pole of the earth, and its south-seeking pole to the earth's north-magnetic pole. It is usual and more convenient to employ, instead of a magnet, a magnetic needle for experimental purposes. The needle is made of steel and is very light and thin, usually lozenge-shaped, and balanced on a pivot in the manner of that used in the ordinary pocket-compass. It is magnetised by being rubbed with a magnet; and has, of course, a north-seeking and south-seeking pole. These are in common parlance called the North and South Poles, at least in England; but the custom leads to very great confusion of ideas; for if we name that pole of the magnetic needle pointing towards the north magnetic pole of the earth the North Pole, and that pointing towards the south magnetic pole, the South Pole, we virtually state that like poles attract each other, which is the very reverse of the fact, and consequently the terms *north-seeking* and *south-seeking* which have frequently been adopted

by English men of science are far more correct, and will be used in the present work.

A magnet always has two poles, one north-seeking and one south-seeking; it is quite impossible to obtain a magnet with one pole only; but a *magnetic substance*, viz. a substance which, like iron, has the power of attracting and being attracted by a magnet, has no poles, neither does it appear to have any force of repulsion, for it is equally drawn to either pole of the magnet which may be presented to it. Iron and steel are not the only magnetic substances, nickel and cobalt show the same properties, but in a very inferior degree, and some other metals, as well as paper, porcelain, and oxygen gas are feebly attracted if exposed to the influence of a very powerful magnet.

It was for a long time supposed that those substances not attracted by a magnet were not influenced by it at all, but experiment has proved that if subjected to strong magnetic action they are repelled, or at least appear to be so. Bismuth possesses this property in the most marked degree, and a small bar of bismuth suspended between the poles of two powerful magnets,¹ turns itself so as to lie at right angles to the line between the poles, thus

¹ Electro-magnets, which will be described in a future chapter, are employed in these experiments.

getting as far away from them as possible.¹ A bar of iron or steel suspended in the same manner would, on the contrary, turn along this line so as to present its ends to the poles, thus approaching them as closely as it could. Substances which appear to be repelled by magnets are called *diamagnetic*.²

By *magnetic force* is meant the force with which a magnet attracts or repels another magnet, or with which it attracts a piece of iron or of any magnetic substance. This force decreases with distance, and between two magnet poles it is directly proportional to their strength, and, if they are very small and far apart, inversely proportional to the square of the distance between them.

It is easily understood that the attraction between two unlike magnet poles is mutual. Each is drawn towards the other, but perhaps it is not quite so evident that the attraction between a magnet and a magnetic substance, a lump of iron for instance, is also mutual. At any rate, the popular idea is that

¹ This behaviour of the bismuth and of other diamagnetic substances has, however, been shown to be due, not to their being really repelled, but urged into the weakest part of the magnetic field. Substances which are faintly magnetic behave as though they were diamagnetic, if immersed in a medium more magnetic than themselves.

² Thus named because they allow the magnetic forces to act across them, which "magnetic," or as they are often called, "paramagnetic" substances will not do.

the magnet attracts the iron, but we do not hear of the iron attracting the magnet. Yet this is equally true, for if a magnet be balanced on a piece of cork and set floating in a basin of water, and a lump of iron be held near the edge of the basin, the magnet will immediately move towards it, just as we should see the iron move towards the magnet if their positions were reversed. Moreover, the action and reaction between a magnet and a magnetic substance are equal, just as the action and reaction between two magnets are equal. The fact is that a magnetic substance is one in which a magnet can induce temporary or permanent magnetism of the opposite kind to that of the pole presented to it, and this is the cause of the mutual attraction.

Magnetic induction can only take place in magnetic substances, just as electric induction can only take place in conductors; and here we may remark on the great likeness existing between some of the fundamental phenomena of electricity and magnetism. Electrified bodies can attract and can repel, so can magnets. Electrified bodies can induce electricity in other bodies; magnets in like manner can induce magnetism. Yet, though there are great similarities, there are also great differences. An electrified body has no poles; its power of attraction and repulsion resides all over its surface. Moreover, an electrified

body electrifying another by contact, electrifies it in the same way as itself, and parts with some of its own original charge to do so. A magnet behaves quite differently, its poles always magnetise in the opposite way to their own magnetism, whether by contact or by influence, and no magnet ever loses any of its magnetism by imparting it to another body. It remains quite as powerful after as before the operation. Neither can it be said that magnetism and stationary electric charges show the slightest relationship to one another,¹ though, as we shall hereafter see, electric *currents* and magnetism appear to be very closely connected indeed ; and since current and static electricity have been proved to be the same agent manifesting itself under different conditions, we may justly infer that magnetism is not of a wholly different nature from either.

Magnetic induction will take place through any substance, provided it be not itself magnetic. A magnet enclosed in glass, or wood, or immersed in water will equally exert its power of attraction and repulsion. But it cannot do this across thick iron, and a magnet placed within a thick hollow iron ball, is incapable of influencing, or being influenced by any outside

¹ It appears that if a magnet and a charged body are in relative motion, a very slight interaction occurs, tending to make them revolve round each other.

magnet. The reason of this would appear to be that the action and reaction between the magnet and the iron employs the whole magnetic force of both, and therefore none can penetrate beyond the iron. Magnetic induction can take place across a vacuum, thus showing that the presence of ordinary matter is not necessary to the transmission of the magnetic forces, and that the real medium by which they are conveyed is the ether.

As has already been stated, there are various ways of making magnets. The simplest, but not the best, is by stroking the bar or needle of steel to be magnetised from end to end with a lodestone or steel magnet. This is called magnetisation by single touch. Another and better way is to use two magnets, commencing by placing their opposite poles together in the centre of the bar to be magnetised (which is laid in a horizontal position), and then drawing them along to the ends, repeating the operation several times over. This is called magnetisation by divided touch. *Both* sides of the bar should be subjected to the same treatment, and care taken that it is methodically and regularly followed out, otherwise there may be points between the true poles where other poles will be formed, called *consequent poles*, thus weakening the external influence of the magnet through the reaction of the consequent poles

on each other. Magnets can be made by the action of the earth's magnetism on bars of steel held in the magnetic meridian, *i.e.* with one end directed towards the magnetic north, and the other towards the magnetic south pole of the earth, and struck by a wooden mallet while in this position. A bar of steel raised to a red heat, and allowed to cool while lying in the magnetic meridian, also acquires magnetic properties; but by far the most powerful magnets are made by placing a bar of steel or iron inside a coil of wire, through which an electric current is caused to pass. The steel is made into a permanent magnet by this operation, but the soft iron only retains the whole of its magnetic properties while the current is passing. During this time, however, it becomes magnetised to a very high degree indeed, and these electro-magnets, as they are called, are by far the most powerful of any, and will be described and explained in a later chapter. Magnets which have been magnetised to the highest degree of which they are capable, are said to be *saturated*.

A magnet can be made of any shape, but the bar and the horse-shoe are the most common. Instead of a bar a bundle of steel wires may be magnetised, and will act as one magnet. These *laminated magnets* are stronger than single bars, provided the wires be magnetised separately before being put together.

A thin sheet of metal may be so magnetised that the whole of one face of it will possess north-seeking, and the whole of the opposite face south-seeking magnetism. Such an arrangement is called a magnetic shell, and is of considerable interest and importance, because it in many respects greatly resembles a closed voltaic circuit.

By the *strength* of a magnet is meant the amount of magnetic force it possesses, *i.e.* the power of attraction and repulsion shown by its poles; but the *lifting-power* of a magnet is a different thing. It signifies the weight which a magnet is able to support, and that depends on the surfaces of contact as well as on the strength of the magnet. A horse-shoe magnet has much more lifting-power than a bar magnet, for the simple reason that both its poles are pressed into the service, whereas with a bar magnet one only can be employed for this purpose.

Though steel once magnetised becomes so permanently, as we have seen, there are, nevertheless, circumstances under which it cannot retain its magnetic properties. They are weakened if the steel is very much heated, though partially recovered as it cools, and lost altogether if it is made red-hot. If the ordinary temperature of a steel magnet is lowered, on the contrary, its strength increases, unless the cold to which it is subjected be very extreme

indeed, when it loses its magnetisation.¹ The same thing happens if it is roughly used and knocked about; and this seems to point to the conclusion that magnetism is closely connected with molecular structure. A far more convincing testimony is borne to this theory, however, by the effect of rupture on a magnet. The latter appears, as has been stated, to have no magnetic force at its centre. Nevertheless, if a magnet is broken in half, each half will be a perfect magnet with a north-seeking and a south-seeking pole, and if the halves be broken in their turn, four perfect magnets will have taken the place of the single original one. In fact, the process may be repeated indefinitely, and if the single magnet were to be broken a hundred or a thousand times, each piece, however small, would still be a perfect magnet.

Only one theory has been put forward which seems to give a satisfactory explanation of this phenomenon. This is, that every molecule contained in a magnet is itself an infinitesimal magnet with a north-seeking and a south-seeking pole, and that the state of magnetisation consists in all the molecules being turned the same way—set end to end as it were, so that the north-seeking poles all

¹ Professor Silvanus Thompson states that a steel magnet brought down to a temperature of 100° C. below zero loses its magnetic properties. — *Elementary Lessons in Electricity and Magnetism*, p. 84.

point in one direction, and the south-seeking poles in the opposite direction. The inevitable result of such an arrangement would be, that the magnetic force would always appear to lie at the ends of the magnet, and yet that it could be divided into any number of perfect magnets.

There are other phenomena besides those already mentioned which support the molecular theory of magnetisation. A bar of steel when magnetised slightly lengthens, thus showing that there is a change of arrangement in the molecules, and that it must be one which places them parallel to each other. Water, rendered muddy by being mixed with fine magnetic oxide of iron, becomes, when magnetised, clearer in the direction of magnetisation, as though light were able to pass better by reason of the parallel arrangement. A metallic clink is also heard when iron is magnetised and demagnetised, and when this is rapidly done it becomes hot, showing that internal friction must take place.¹

The space all round a magnet within which the magnetic forces make themselves felt is called a

¹ Since the above was written, Professor Ewing has given, in a paper on magnetic induction, communicated to section A at the meeting of the British Association at Leeds, 1890, an account of some highly interesting and important experiments, which appear to place the molecular theory of magnetization on a much firmer basis than has ever been the case before. It may, in fact, be said to be to a great extent proved.

magnetic field, and the directions along which these forces act have been called *lines of force*. Their shapes differ according to the number, position, and shape of the magnets forming the field.

Figures of these lines of force are obtained by placing a sheet of paper over a magnet, and then sifting very fine iron filings through a muslin bag over the paper. They arrange themselves in beautiful curving lines, each particle taking up the posi-

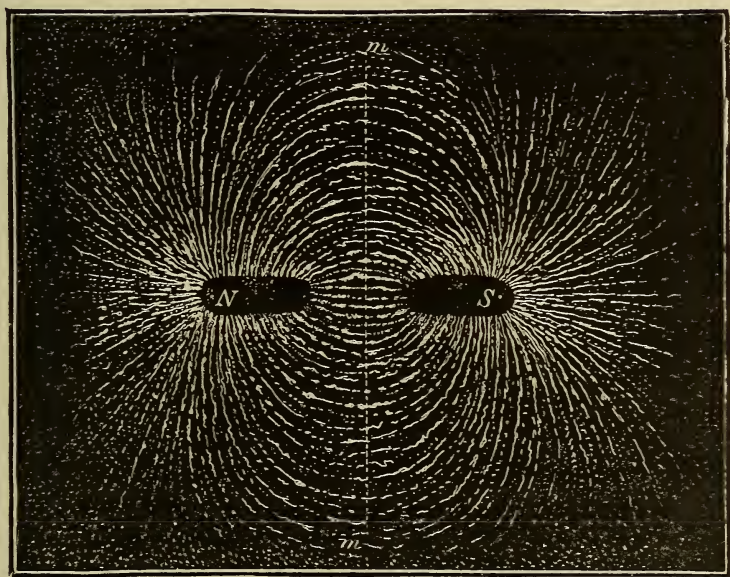


FIG. 11.—Lines of force in a magnetic field formed by a single bar magnet.

tion assigned to it by the combined action of both poles, so that at every point of the lines the resultant direction of the attractive and repulsive forces is

accurately shown. Fig. 11 gives the curves of the lines of force in a magnetic field formed by a single



FIG. 12.—Lines of force in a magnetic field formed by two bar magnets, with north-seeking and south-seeking poles confronting each other.

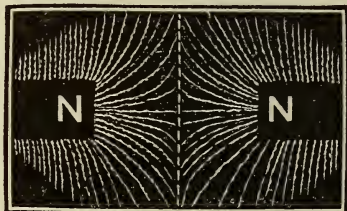


FIG. 13.—Lines of force in a magnetic field formed by two bar magnets, with north-seeking poles confronting each other.

bar magnet; Fig. 12 shows those in a field containing two bar magnets with opposite poles confronting each other; Fig. 13 those where similar poles confront each other. These two last figures illustrate most strikingly the action of the attractive and repulsive forces. The lines from the opposite poles which attract each other, curve inwards so as to enter the one pole from the other; the lines from the similar poles which repel each other curve outwards, turning aside at right angles so as to get as far away as possible.

The size and strength of a magnetic field depend on the strength of the magnet or magnets contained in it, and on their position with regard to each other. The strength is always greatest near the poles. Any magnetic substance placed in the field becomes for the time magnetised by induction.

CHAPTER II

MAGNETISM OF THE EARTH

Gilbert discoverer of the earth's magnetism—Oscillations of magnetic needle before settling itself in the magnetic meridian—Magnetic intensity—Magnetic poles of the earth—Declination of the needle—Variations in the declination and their causes—Line of no variation—Isogonic lines—Inclination of the needle—Inclination compass—Magnetic equator—Isoclinic lines—Magnetic maps—Fluctuations in the earth's magnetism—Periodicity in the occurrence of magnetic storms—Influence of the sun on terrestrial magnetism—Effect of the earth's magnetic force on the magnetic needle, directive only—Magnetisation of steel and iron objects by the earth—Magnetism of iron ships.

THE honour of first discovering that the earth itself is a large magnet belongs to the same Dr. Gilbert whose name has already been several times mentioned. As we have seen, a magnet or magnetic needle when freely suspended, *i.e.* hung from, or balanced on the point, which is its centre of gravity, takes up a particular position with regard to the earth, turning itself so as to lie in the magnetic meridian. It does not do this with one steady movement, but undergoes

a series of oscillations before finally reaching its position of equilibrium, and every time it is moved or disturbed the oscillations are repeated. By making calculations on the number which occur in one minute, the strength of the earth's magnetism, called its *magnetic force* or *intensity*, at the particular locality can be discovered, though it must be remembered that the weight, shape, and length of the magnet have to be taken into account, the number of oscillations executed in a minute depending on them as well as on the strength of the earth's magnetism.

From the fact that the magnetic needle does not point due north and south, we may infer what is in fact actually known, that the earth's magnetic poles do not coincide with its geographical poles. The north magnetic pole is situated just within the Arctic Circle in Lat. $70^{\circ} 5' N.$, Long. $96^{\circ} 46' W.$ The south magnetic pole has never been discovered, and from various indications it is thought that there may be two. The angle made by the magnetic needle with the geographical meridian is called its *declination*, and this is continually varying. The north-seeking pole lies at present to the west in Europe and Africa, and to the east in Asia and the greater part of North and South America. Some of the variations in the declination of the needle take place gradually through a number of years, some annually and

daily,¹ and some are the result of sudden electric and magnetic disturbances, such as displays of the Aurora Borealis, earthquakes, and volcanic eruptions. Thunderstorms and ordinary atmospheric perturbations produce no such effect, however. These accidental variations in the declination of the needle are known as magnetic storms, and are sometimes very marked indeed. Magnetic storms are always attended by a display of the Aurora Borealis in northern latitudes, and are sometimes simultaneous at widely-distant places on the earth's surface.

There are certain parts of the earth where the magnetic north and south do actually coincide with the geographical north and south, and at these places there is no declination of the magnetic needle. They are connected by an imaginary line called a line of no declination, or *agonic line*, which passes round the earth, nearly from north to south, cutting the Equator at right angles. Besides the agonic line there are a number of other imaginary lines called *isogonic lines*. Each one of these connects places on the earth's surface where the declination is the same. A map drawn out representing the isogonic lines is called a declination map,² and is of great service to

¹ The daily variations follow the course of the sun, or rather seem to make an effort to do so, for they are very slight.

² That is to say, it is so-called by scientists. Sailors know it as a "variation" map.

mariners, whose compass is in like manner called a declination compass. It is not known who was the first inventor of this valuable instrument, but it was in general use in Europe in the thirteenth century, though in a much more primitive form than any with which we are familiar. It consisted merely of a magnetic needle set floating in a basin of water by means of a cork or of two straws, and nothing then was understood about "declination," the needle was supposed to point due north and south.¹ Hundreds of years before the compass was used in Europe, it was known to the Chinese, who navigated their ships by means of a magnetic needle pointing south, and it is even stated by Humboldt that 1000 years B.C. the Chinese had magnetic carriages in which to find their way across the plains of Tartary. The compass consisted of the figure of a man with a movable arm pointing to the south.

Besides setting itself in the magnetic meridian, there is another peculiarity to be remarked in a freely-suspended magnetic needle, namely, that if placed in a horizontal position, its north-seeking pole dips downwards in the northern hemisphere, and its south-seeking pole in the southern hemisphere. This fact was first discovered in 1576

¹ Columbus is supposed to have been the first European to discover the declination of the magnetic needle.

by a scientific instrument-maker named Norman, and he constructed an *inclination compass* or dip needle, designed to show the angle of dip or inclination which the magnetic needle makes with the horizon. Far more delicate and accurate instruments are now in use at Kew and other great observatories, where daily and minute records are kept of the three magnetic elements, as they are called, namely, the intensity of the earth's magnetism at the particular spot, and the declination and inclination of the needle.

Just as there are places where there is no declination, so there are places where there is no inclination, and these are situated at the farthest possible distance from the magnetic poles. The imaginary line which connects them, therefore, roughly follows the course of the geographical equator, cutting it at two points almost exactly opposite to each other, and situated one in the Atlantic and one in the Pacific Ocean. This line is called the *magnetic equator* or *aclinic line*. *Isoclinic lines* are those which connect places on the earth's surface where the inclination of the needle is the same. At the north magnetic pole the inclination needle is vertical, and could the south magnetic pole be reached its position would of course be the same there. We have therefore very clear evidence that the magnetic force affecting the needle does really reside in the earth itself and not at any point above

its surface, for were this the case there would be no inclination. Fig. 14 is a magnetic map of the world

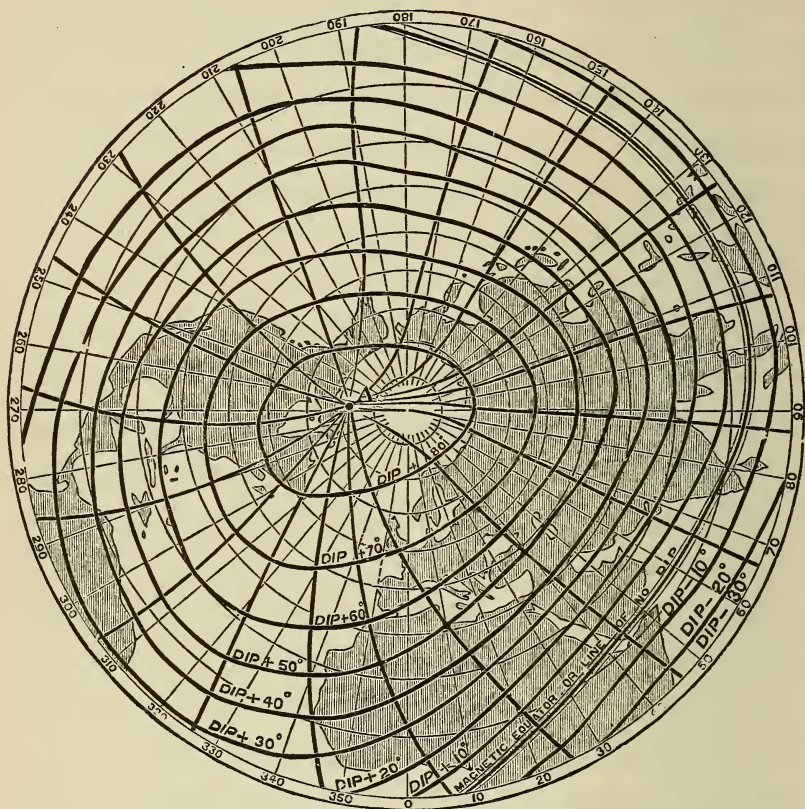


FIG. 14.—Magnetic Map of the Northern Hemisphere. A, North Magnetic Pole.

showing both the isogonic and isoclinic lines of the northern hemisphere. It is not possible, however, to construct such maps accurately once for all like geographical maps. The inclination, like the declination of the needle, undergoes annual and other

variations, and in fact the minute and careful observations which have been made of late years show that the magnetism of the earth is in as continual a state of fluctuation as the waters of the ocean.¹ Nevertheless, it is possible to determine what these fluctuations are likely to be for a few years in advance, and to construct maps which will hold good approximately for that length of time. The close study accorded to terrestrial magnetism has brought out many curious facts concerning it, one of which is a certain periodicity in the appearance of magnetic storms which makes their greatest frequency coincide with the maximum period of sun-spots, *i.e.* every ten or eleven years. It would seem, in fact, that there is some remarkable connection between the sun and the earth's magnetism. One specially striking proof of this occurred in 1851, when a luminous mass was seen to cross a sun-spot, and at the same time the magnetic needle at Kew underwent great perturbations. Subsequent inquiries brought to light the fact that at the same moment one of the most violent magnetic storms ever known was going on in various parts of the earth.

¹ These fluctuations in the magnetism of the earth cause what are known as "earth currents," often very troublesome in telegraphy. They always occur during magnetic storms, and there are also exceedingly weak daily earth currents, flowing from the magnetic poles towards the equator.

Before closing this chapter it is necessary to call attention to the fact that the effect of the earth's magnetic force on the magnetic needle is simply directive, causing it always to take up a particular position, but not imparting to it any power of locomotion. This is proved by observing the behaviour of a floating magnetic needle. It does not move towards the north, though it sets itself so as to point in that direction. Yet if we were to hold a magnet near the edge of the vessel, the needle would instantly move towards that, which seems to necessitate an explanation of its different behaviour with regard to the earth. The fact is that in ordinary cases the needle moves towards the magnet because the nearer pole of the latter acts more strongly on one pole of the floating needle than on the other. In the case of the earth, however, both its poles are so far away from the needle that the one which is nearest exerts equal and opposite forces on the latter, forming what is called the *terrestrial magnetic couple*, tending to turn the needle round but not to cause any movement of translation.¹

It has already been stated that the earth is able to induce magnetism in steel or iron bars, but, in fact,

¹ Any two equal forces acting in opposite parallel directions to each other, on a rigid body tend to produce a movement of rotation.

any steel or iron objects or masses of those metals are affected in the same way. Fire-irons which have been allowed to stand for a considerable time in a vertical or inclined position become magnetised, the lower end being a north-seeking and the upper end a south-seeking pole,¹ and the same remark applies to railings, lightning-rods, etc. Objects made of steel or of cast iron retain this state of magnetisation, but pure, soft iron cannot do this, as it possesses no *retentivity*, or *coercive force* as it is called. For this reason a bar of soft iron magnetised by the earth has the magnetism of its poles immediately reversed with the reversal of their position if it be tapped, that which was a north-seeking becoming a south-seeking pole if turned upwards. This phenomenon is very rarely observed, however, in common objects, as the ordinary iron of commerce is not perfectly pure, and therefore possesses a slight retentivity, even the tools in a smith's shop showing faint signs of magnetisation.

The most important effects produced in this way by the earth's magnetism are those on iron ships, which during the process of building become, owing to the hammering they receive while under the influence of the earth's magnetism, permanently magnetised, and consequently able to exert a disturb-

¹ That is, in the northern hemisphere. In the southern the reverse would be the case.

ing influence on the compass-needle, which is thus in many positions of the ship unable to lie in the true magnetic meridian. Such a result is of course disastrous to navigation, and various methods of obviating it are resorted to. The use of compensating magnets, *i.e.* masses of iron placed in such a position with respect to the compass that they neutralise the effect of the ship's magnetism on it, is one; but here a difficulty arises from the fact that after a first voyage the magnetism of the ship generally alters, becoming less strong than it previously was owing to the buffeting of the waves. In fact, for a considerable period every voyage makes a difference to the ship in this way, and the compensating magnets have to be frequently altered lest they in their turn should disturb the compass-needle by over-compensating the magnetism of the vessel. Fortunately, after a time this does become really fixed, but until then so great are the difficulties attending the use of compensating magnets that they are frequently dispensed with, and a table of errors drawn up by careful observation of the magnetism of the ship and continual comparison with the indications of the compass-needle is trusted to instead. In the Royal Navy both methods are employed. The extreme importance of care in this respect is demonstrated by the fact, that the loss of ships has been known to occur owing to errors in the compensating

magnets which rendered the compass directions untrue. Such a disaster has, however, never occurred in the Royal Navy,—a fact on which the authorities justly pride themselves.

Frequently a standard compass is placed in the masts, so that it may be as far removed as possible from the influence of the ship's magnetism.

PART III

CURRENT ELECTRICITY

CHAPTER I

THE GALVANIC BATTERY

Definition of an electric current—Direction of the current—Galvanic battery—Description of simple voltaic or galvanic cell—Effects of the current—Its cause—Poles—Electro-motive force—Resistance—Ohm's law—Difference between electro-motive force of cells in series and in parallel—Weakening of current through polarisation—Daniell's cell—Grove's and Bunsen's batteries—Principle common to all batteries—Secondary batteries—Possibility of obtaining them due to polarisation—Self-induction—"Extra-current" effects—Space surrounding wire conveys the electric current as well as the wire itself—Nature and effects of an electric current the same from whatever source it is supplied—Thermo-electric currents and the thermopile.

It can hardly be said that in the section devoted to static electricity no mention was made of currents, for all discharge was shown to be a flow, and flow is but another word for current. That which takes

place in discharge, however, is momentary, and by a current of electricity a *continuous* flow is nearly always understood. This continuous flow is caused by a maintained difference of potential between one point and another, and when once set up it does not cease until the potential is equalised, any more than a river would cease flowing unless its whole bed became level, or its springs were dried up.

By the direction of an electric current is invariably meant *the flow from positive to negative*, though it must not be forgotten that there is always a negative current as well, whose course is exactly opposite, *i.e.* from negative to positive. In practice this is usually entirely ignored, a fact which does not render it one whit the less important and interesting to those whose inquiries turn towards the nature of electricity. No satisfactory theory can be propounded which does not take into account the double current.

One of the easiest and most familiar ways of producing an electric current is by means of the *Voltaic* or *Galvanic battery*, discovered towards the close of the last century by the researches of two eminent Italian scientists, Volta and Galvani, working independently of each other and on some theoretical points diametrically opposed.

A battery consists of a larger or smaller number of cells or "elements" exactly like each other, and

the following is a description of the earliest form of cell. A strip of copper and a strip of zinc are placed, not touching each other, in a glass or porcelain vessel containing an acid liquid (a very weak solution of sulphuric acid is generally used), and are connected by copper wires, starting one from the zinc and the other from the copper plate (Fig. 15). When these

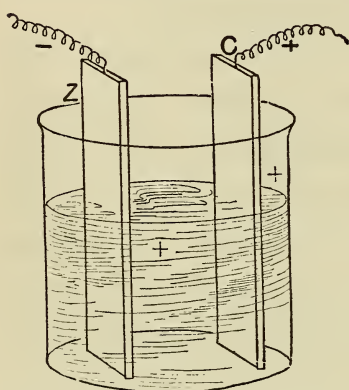


FIG. 15.—Single Galvanic Cell, indicating the direction of the current through the liquid and wires. Z, zinc plate; C, copper plate. The terminal wires join Z to the copper plate of an adjoining cell, and C to the zinc plate of an adjoining cell.

wires are joined a current of electricity is set up which flows from zinc to copper through the liquid, and from copper to zinc through the wires, that is right round the circuit, and it continues to flow thus till the wires are disconnected. The junction between the wire and the copper plate is called the positive pole or *electrode*, because it is there that the positive current *through the*

wires begins, and the junction between the wire and the zinc plate is called the negative pole or electrode. This current produces all the same effects as a discharge. The magnetic needle is deflected by it, chemical decomposition is caused, a thin wire becomes heated, and if the ends of the two wires are placed on the tongue

a peculiar taste is noticed. All these effects are greatly enhanced by placing a number of cells in series, connecting the zinc plate of one to the copper of the next, and so on, the wires being fixed to the terminal zinc plate at one end and the terminal copper plate at the other. When the cells are thus connected, the current flows from one to the other, but they may be arranged *in parallel*, i.e. all the zinc plates connected to each other, and all the copper plates to each other. The current then divides itself between the cells.

At this point the question naturally arises, What causes the current? A long and fierce war, perhaps hardly yet terminated, was waged by the disciples of Volta and Galvani respecting the right answer to be given. The former maintained that the current was due to contact of dissimilar metals, the latter to chemical action, and since both these causes exist in the battery, and both produce difference of potential, which is as necessary to the existence of a current as difference of level is to a flow of water, it seems very difficult to decide between the two. Probably the right way of addressing the disputants would have been in the words of the traveller called upon to arbitrate in the far-famed quarrel concerning the colour of the chameleon,

“You both are right and both are wrong.”

It probably is the contact of dissimilar metals which causes the difference of potential in the first instance, and the effort to maintain this potential difference requires chemical action, so that the chemical action, to be presently described, maintains the continuous flow.

The work done in a galvanic battery may be compared to the work done by a pump. The pump raises water from a low to a high level, in opposition to the natural tendency of water to flow from a high to a low level. Work is thus expended *on* the water which is reproduced, minus the amount wasted in friction in the pump, *by* the water as it flows back to its original level. In a galvanic battery electricity is raised from a low to a high potential, in opposition to its apparent tendency to flow from a high to a low potential. Work is thus done *on* electricity which is reproduced, minus the amount wasted in overcoming the resistance of the battery cells, *by* electricity as it flows back through the outer circuit to its original potential. What happens *inside* the cells of a battery, then, is that an electric current is driven against a difference of potential (or of electric level), and that a difference of potential is consequently produced and maintained between the terminals or electrodes of the battery. What happens *outside* the battery is that a flow of elec-

tricity takes place between the terminal at high potential to that at low potential, so that the direction of the current is with the slope of potential, and work is done by it on its road. Electricity is raised from a low to a high potential inside the battery, and caused to flow from a high to a low potential in the same circuit outside the battery, by what is called *electro-motive force*. No electric current can exist anywhere without an electro-motive force, and since in very many instances it may also be said that no current can exist without a difference of potential, these two terms, electro-motive force and difference of potential, are often regarded as interchangeable. Yet they do not express the same thing. Electro-motive force may cause, or may be the result of, difference of potential, or may exist without it, whereas difference of potential cannot exist without electro-motive force. Moreover, it is necessary to remember that though electro-motive *force* is thus named, it is not, accurately speaking, a force at all. It does not act on matter, which is the characteristic of force. It acts on electricity, whatever that may exactly mean. And perhaps the most comprehensive definition which can be given of it, is that it is "the ratio of the rate of doing work in the circuit to the current flowing."

It has already been stated that, however good

the conductor through which an electric current is flowing may be, the latter always encounters a certain amount of obstruction or *resistance* on its road, which may be considered analogous to friction in the case of ordinary matter. The power of the current to overcome this resistance, depends on the force with which it is being driven along (on the electro-motive force), and the strength of the current, by which is meant the quantity of electricity flowing per second past a cross-section of the conductor conveying the current, increases in direct proportion to the increase of potential difference. It was ascertained first by Ohm, and has since been carefully proved by others, that in a metallic conductor of the same material, dimensions, and temperature, the ratio of potential difference to current-strength never changes, and may be called the *resistance* of that particular conductor. This statement is known as *Ohm's law*, and has now been proved true for liquids. Its various applications are of the greatest importance and interest to practical electricians.

When the cells of a battery are connected in series, the sum of their respective electro-motive forces is the electro-motive force of the whole battery. When they are in parallel, the electro-motive force of one cell equals that of the battery. The electro-motive force of any cell is independent of its size,

and is affected only by the materials of which it is made.

The current in the earlier batteries could only be maintained a short time, owing to the rapid decrease in its strength caused by the very chemical action which produced and sustained it. This chemical action consists in the dissolving of the zinc in the acid, by which means sulphate of zinc is formed, and hydrogen gas set free. The latter forms in bubbles on the copper plate, and there does a two-fold mischief. In the first place, being a bad conductor, it greatly diminishes the effect-iveness of the copper; in the second, being itself an electro-positive substance (becoming positively electrified by contact with other substances), it

tends to set up an opposing electro-motive force in the battery; in other words, a second positive

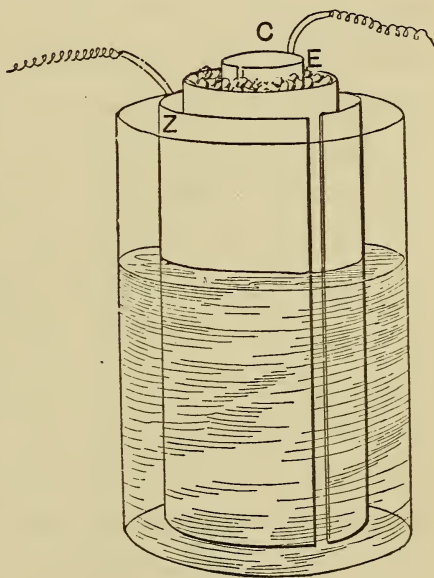


FIG. 16.—Daniell's Cell. Z, zinc plate; C, copper plate; E, porous earthenware partition. The vessel containing the liquid is represented as made of glass, but glazed stoneware is very frequently used, and a zinc rod often takes the place of C in the figure, the copper plate being then situated at Z.

current flowing in an opposite direction to the first, and consequently much weakening its action. A battery in this condition is said to be polarised, and various cells have been made by different electricians to prevent its occurring, and so render the current *constant*, *i.e.* enable it to maintain the same strength for a long time together. Daniell's (Fig. 16) was the first, and both it and various modifications of it are still much used. Instead of one, two liquids are employed in it, one in contact with the zinc, and one with the copper plate, which are sometimes rolled cylinder fashion, and divided by a porous, unglazed earthenware partition. The liquid which is in contact with the copper plate contains sulphate of copper as well as sulphuric acid. The effect of the whole arrangement is to intercept the hydrogen on its road, and instead of it, particles of copper drawn from the sulphate of copper contained in the liquid are deposited on the copper plate, which consequently cannot lose in efficiency.

Another form of battery much used is Grove's, where platinum is substituted for copper. Though capable of maintaining a current of the same strength for several hours at a stretch, the expense of the platinum constitutes a disadvantage in this battery; and Bunsen contrived one greatly used in laboratory experiments in which graphite, hard gas carbon

obtained from the interior of gas-retorts, is used instead of either platinum or copper.

There are many other batteries unnecessary to describe here, their suitability varying with the purpose for which they are employed. One principle, however, is common to all. No battery can produce a current giving sensible effects unless there is a sensible consumption of its materials by chemical action, any more than a fire will give out sensible heat without a sensible consumption of coal. The material which is "burned" in a battery is generally zinc, which being almost at the head of the electro-positive series (see p. 39) and very readily oxidisable,¹ has not hitherto been replaced by another less expensive substance. In consequence of this it was found impossible to utilise electric currents on a large scale in any work, such as electric lighting, where powerful currents were required, till some other method than that of galvanic batteries could be employed to generate them, for the consumption of material being proportional to the strength of the current, a large quantity of zinc must be used up in order to produce a powerful current for a considerable time. In telegraphy, where a weak current suffices, this

¹ It is absolutely necessary that one of the metals employed in a battery should have a great affinity for oxygen, as it is this affinity which first starts the chemical action in the cells.

objection does not apply. It should be mentioned that it is necessary to use either perfectly pure or amalgamated zinc, otherwise chemical action goes on, and the zinc dissolves even when the current is not passing, which "local action," as it is called, causes much needless waste.

Before quitting this subject, mention must be made of what are called *secondary batteries*, in which the energy of a current may be stored up as chemical work, and again given out in the form of electric energy. They are also called *storage batteries*, and an opinion is often held by the unscientific that electricity itself is stored. Such is not the case, however; it is the energy of the current which is stored in the form of the products of chemical decomposition, and when this stored-up energy is freed, an electric current is again set up and chemical recombination begins. A secondary battery cannot commence to work of itself. It needs in the first instance to be "charged," *i.e.* a current must be passed through its cells from an external source, in order to produce the chemical decomposition in which the work of storage consists. When this has been done for a sufficient length of time, the two batteries are separated, and the poles of the secondary being connected, a current is immediately set up, having all the properties of, and being able to perform the same

work as that from an ordinary galvanic battery. There is no necessity to use the secondary battery at once; it will remain "charged" for a considerable time, and in this fact consists its importance and convenience. The method of charging by a galvanic battery, however, is very expensive, and in consequence no wide use could be made of the storage principle until other means of charging were available. The dynamo machines, to be described in a future chapter supplied this want, and secondary batteries have consequently come into great request, being specially useful in electric lighting and locomotion.

The possibility of obtaining secondary batteries is really due to polarisation. We have already seen (p. 145) how an opposing electro-motive force may be set up in an ordinary battery by the deposit of hydrogen on the negative electrode, causing after a time a second positive current flowing in an exactly opposite direction to the first, and so weakening its action. It is this, the polarisation current, which is utilised in secondary batteries, and consequently the current in them flows always in the opposite direction to that of the charging battery. Ritter first discovered the principle of secondary batteries, called also accumulators, in 1803, and many years after the eminent French electrician, Gaston Planté, showed

how it could be turned to practical use. Faure's storage battery, an improvement on Planté's, is now most generally used.

It is usual and convenient to speak of the conducting wires as though they alone conveyed the current, but theoretically, and as a true explanation of what happens this is not the case. We have already seen what an important part is played in the phenomena due to static electricity by the insulating medium, and its function in the case of electric currents is equally necessary, for it will easily be understood that though the wires *appear* to convey the current, the surrounding space must take part in the action also, because within such a space the magnetic needle is affected, and other magnetic and electric phenomena occur. We cannot therefore regard the wire so much as a sort of pipe through which something or other is passing, as the centre of a disturbance in the ethereal medium, which disturbance is propagated along the outside as well as through the wire. It is, in fact, now considered that the energy of an electric current travels entirely through the insulating medium, and not through the wire at all, the function of the latter being to dissipate, not to transmit, the energy it receives. By this dissipation, however, it enables the surrounding medium to continue transmitting more energy, instead

of taking up a passive strained condition, such as exists, for instance, in the dielectric layer of a condenser.

This fact, that it is really the space round the wire, and not the wire itself, which conveys the energy of an electric current, explains a phenomenon which was for some time not understood, viz. that an electric current does not instantaneously rise to its full strength when circuit is made, nor instantaneously cease when it is broken. A very slight, but still measurable, delay occurs in both instances, and in the latter the sudden breaking of the circuit will often occasion sparks, showing that the current, unable to stop at once, bursts through the insulating medium interposed with an outbreak of heat and light. Water, which has been several times used as presenting an analogy to electrical phenomena, affords one also here. Water enclosed in a pipe cannot be set in motion suddenly, or if already in motion cannot be suddenly stopped, except by the exertion of a force which is very likely to burst the pipe. With water these two effects are due to inertia, a universal property of matter which can neither start nor stop moving unless force be brought to bear on it. Since an electric current exhibits the same peculiarity, we are naturally led to ask whether that also possesses inertia,

and the interest of the question lies in the fact that if it did, electricity would be proved to be a form of matter, however widely different that form might be from those with which we are familiar. But though in the instances cited above (which used formerly to be called "extra-current" effects), electricity appears to possess inertia, in other equally important ways it seems entirely devoid of it. Inertia where it really exists produces well-defined mechanical effects, and examined by any mechanical means an electric current shows no sign of it. The fact is that the effects observed on making and breaking circuit, as well as others of a similar nature, are due not to the inertia of electricity, but to the electro-magnetic inertia of space (or rather of the medium which fills space), and this is quite a different thing. As we have seen, the space surrounding a wire conveying an electric current acquires the property of producing magnetic effects. Such a space must therefore be in a state of magnetisation; but it neither acquires nor loses this condition instantaneously, and in consequence causes those phenomena (known as self-induction phenomena,) which appear to be due to the inertia of the current itself.

In whatever way an electric current is given rise to, its nature and effects are essentially the same; and therefore though one source only, the galvanic

battery, has yet been described, it will be well to give in the ensuing chapters some more detailed account of the various effects produced. Before doing so, however, a brief mention may be made of what are called *thermo-electric currents*. These arise from setting up a difference of temperature between two junctions formed of two different metals, the effect being more marked when bismuth and antimony are used than with any other metals. Two metals joined for the purpose of giving rise to an electric current through inequality of temperature are called a *pair*, and a number of these pairs may be united so as to form a kind of battery, which is known by the name of a *thermopile*, every alternate junction being either heated or cooled above or below the temperature of the rest of the circuit. When a difference of temperature is set up between two junctions of bismuth and antimony the current flows from bismuth to antimony across the hotter junction, and from antimony to bismuth across the colder, the hotter junction being cooled and the colder warmed during the process, so as to bring them to the same temperature as the rest of the circuit, when the electro-motive force (called *thermo-electro-motive force*), and consequent difference of potential, causing the current cease. The currents thus produced are of a low electro-motive force,

though some thermopiles have been constructed which generate currents strong enough to depose metals from their solutions, and they have even been made of some practical use in this way. The most usual and important function of the thermopile, however, is to act as an extremely delicate thermometer able to indicate the very smallest changes in temperature, and for this purpose it is invaluable.

CHAPTER II

CHEMICAL AND PHYSIOLOGICAL EFFECTS OF THE CURRENT

Difference in the way solid and liquid conductors convey an electric current—Analogy with heat—Electrolytes—Electrolysis—Electrodes—Anions and kathions—Deposition of metals by electrolysis—Electrolysis of water—The voltameter—Free atoms only appear at the electrodes—Gröthuss' hypothesis—Physiological effects of the current—Galvani's experiments—Results of recent experiments—Exciting effect of extraneous currents on living nerves—Difference between the physiological effect of the passage of a galvanic current and a Leyden jar discharge—And of continuous and alternating currents.

Chemical Effects.

AN electric current does not flow in the same way through solid conductors and through liquids. In the former it does not travel *with* the molecules of matter, but in some way *through* them, whether we picture it doing so as water filters through sand, or as passing from one molecule to another like heat. Heat itself, however, travels in two ways, by what we call conduction in solids, and by convection in

liquids and gases. In conduction there is an increased vibration of the molecules communicated from one to the other; in convection there is an actual double journey of molecules, the hot light ones rising to the top, and the cold heavy ones sinking to the bottom. Through most liquid chemical compounds electricity also travels by a kind of convection. There is a double procession of charged atoms, the positive all going one way and the negative the other way, and thus the two kinds of electricity travel with the particles of matter, just as heat does when any liquid is rising in temperature.¹

In order to produce this double procession of atoms, however, chemical decomposition must take place, and all liquids do not undergo this when an electric current is passed through them. It only occurs when the liquid is a conductor, and turpentine as well as most oils are non-conductors. Again, there are liquids which conduct without being decomposed by the process. Mercury and all molten metals belong to this class, but impure water, as well as acid and saline solutions, undergo decomposition whenever a current is passed through them, whether inside or outside the cells of a battery, and they are known

¹ See *Modern Views of Electricity*, by Dr. Oliver Lodge, F.R.S., p. 66.

in consequence as *electrolytes*. The process of decomposition is called *electrolysis*, a name originally bestowed by Faraday, and abbreviated from electroanalysis. The vessel containing a liquid undergoing electrolysis is called an *electrolytic cell*, and the ends of the wires leading from and to the battery, or the strips of metal (usually platinum) to which the wires are connected, and which dip into the liquid, are the *electrodes*. The positive electrode is called the anode and the negative the kathode.

The atoms set free by decomposition and attracted to the respective electrodes have been already mentioned. Faraday gave them the name of ions, those which appear at the anode being *anions* (the ones which go up), and those which appear at the kathode kathions (the ones which go down). The latter are regarded as being electro-positive because they move with the positive current towards the negative electrode, and the former as electro-negative because they move against the positive current towards the positive electrode. All metallic atoms are kathions—that is, they appear at the negative electrode, and several metals have been discovered through electrolysis, by being disengaged from the substance with which they were united, and deposited by themselves at the kathode. Potassium is one of these, and was discovered by Sir Humphry Davy.

When very pure water is submitted to electrolysis, there must be added to it a few drops of sulphuric acid, perfectly pure water appearing to act as a non-conductor. This being done, however, the process of decomposition commences at once, oxygen being evolved at the anode, thereby proving itself to be electro-negative, and hydrogen at the kathode, thus showing that it is electro-positive. Nearly twice as

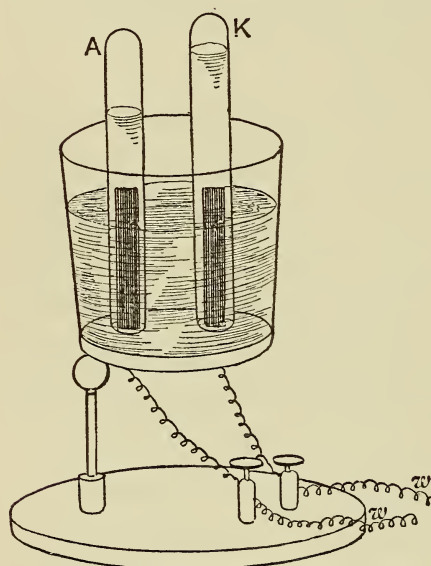


FIG. 17.—Voltameter. A, anode;
K, kathode.

much hydrogen is given off as oxygen in consequence of the chemical composition of water, which consists of two parts of hydrogen to one of oxygen. If it is desired to collect the gases thus set free, an apparatus like that shown in Fig. 17, and known as a *voltameter*, must be used. It con-

sists of a vessel containing slightly acidulated water, in which are immersed two strips of platinum connected by wires with the respective poles of a battery. The strips of platinum are the electrodes of the voltameter, and platinum is used because it resists the action of

every acid, and is not easily oxidisable. Consequently it does not tend to set up other chemical actions besides that of the current in the voltameter. The two inverted tubes over the platinum strips serve to collect the gases; bubbles appear at the surface of the water with which they are originally filled, and as this happens the level of the water sinks, the upper part of the tube over the anode becoming filled with oxygen, and that over the kathode with hydrogen.¹ The voltameter affords a very direct way of measuring the strength of an electric current, because the amount of chemical action which takes place in a given time is directly proportional to the strength of the current, and within wide limits no other consideration need be taken into account. Copper voltameters are frequently used for practical purposes. Two plates of copper are immersed in a solution of copper sulphate (blue vitriol), and serve as the electrodes, that which is to be the kathode having been first carefully weighed. When the current is passed through the cell, particles of copper are drawn from the solution and deposited on the kathode, while the anode gradually dissolves in the exact proportion necessary to replace the copper taken from the solution. After a

¹ The form of voltameter above described, though still frequently seen, is becoming very antiquated, and other better forms have been devised.

given time, the kathode is removed and again weighed, its increase in weight indicating precisely the amount of current that has passed. Though this method of measurement is exceedingly accurate and direct, it can only be adopted in the case of large currents (such as those used in electric lighting), because in the case of small currents, though the amount of chemical action taking place in a given time is always directly proportional to the current strength, it is too minute to be appreciable for many hours, or perhaps days. Weak currents are therefore measured by their magnetic, not their chemical effects, as will be presently described.

There is one very curious fact regarding electrolysis which must not be left unmentioned, viz. that the separated atoms never make their appearance except at the electrodes, and however many cells they may have to pass through before arriving at their respective destinations, nothing whatever is seen of them on the road. The only explanation which seems to account satisfactorily for this remarkable phenomenon is that known as Gröthuss' hypothesis.¹

¹ Gröthuss' hypothesis has been modified in order to meet the further development of chemical science, and it is now more generally supposed that the molecules and atoms of a liquid being always in motion, the passage of an electric current through them controls the direction of that motion, by causing the electro-positive atoms to move towards the kathode, and the electro-negative

He supposed that each molecule of the electrolyte underwent a continual decomposition and recombination. Thus, taking water as an instance, each molecule of which is composed of one atom of oxygen to two of hydrogen, the first molecule decomposed at the positive electrode, sets free one atom of oxygen and two of hydrogen. The latter immediately combine with the oxygen of the second molecule, whose hydrogen is in turn set free, and passes on to combine with the oxygen of the third molecule, which is decomposed and recombined in like manner, and thus the process continues till the negative electrode is reached, where the last two atoms of hydrogen, having no oxygen to combine with, appear free.

Physiological Effects.

Galvani was the first to draw the attention of the scientific world to these, and he himself was accidentally attracted to the subject by observing one day that the legs of some newly-killed frogs underwent violent contractions at every discharge of an electrical machine with which he was experimenting. This effect was due to the "return shock," viz. to the frogs' legs having become charged by induction owing to the near neighbourhood of the electrical machine, towards the anode, thus causing the decomposition of the liquid and the appearance of the free atoms.

and consequently discharging themselves when it did. Not long afterwards Galvani discovered that if a living nerve and muscle are touched by two dissimilar metals in contact, an electric current is set up and the muscle contracts. Subsequently he proved that a single metal would have the same effect, and still later that metal could be dispensed with altogether, and the contraction produced by touching the nerve at two different points with a muscle taken from a living frog. Since his time these experiments have been tried on other animals warm-blooded¹ as well as cold-blooded, and their scope greatly extended. From these researches it has been ascertained, first, that the power of contracting on the passage of an electric current is a distinguishing property of protoplasm, the physical basis of all animal and vegetable life; secondly, that not only do extraneous currents produce certain defined physiological effects, but also that electric currents exist in the living nerves and muscles of all animals, independent of any external stimulus, and that they cease with death, thus establishing an intimate connection between electricity and vital phenomena. What this connection really is, however, remains unknown, and in any case elec-

¹ The experiments are much more difficult to carry out in the case of warm-blooded animals, because their muscles do not retain vitality so long after the general death of the system. Nevertheless the same results have been obtained.

tricity and life are not, as some people seem to suppose, synonymous.

The effect of extraneous currents on living nerves is invariably to excite them to action. Thus, if a feeble current be passed through the eyeball, a brilliant flash of light is seen, owing to the stimulus given to the optic nerve. If the ear be treated in the same way, musical sounds are heard. A current passed through the tongue causes a peculiar taste, and applied to the ordinary nerves of sensation a pricking and stinging are produced. These effects are mostly momentary, occurring only when the circuit is made or broken, but if this be done frequently and rapidly, an equally frequent and rapid succession of the effects may be produced. Where the current is strong enough to cause contraction, tetanus may ensue if the current be interrupted at frequent and rapidly-recurring intervals, owing to one contraction not having time to pass off before another commences. The same effect can be produced by alternating currents (*i.e.* currents flowing alternately in opposite directions).

A galvanic current does not usually give a shock like a Leyden jar, but it will do so, when circuit is made or broken, if the number of cells in the battery employed, is sufficient to give rise to a high electromotive force, for it is the difference in this respect

between a battery and a Leyden jar which causes the difference in their physiological effects. The battery gives out larger quantities of electricity than the Leyden jar, but the difference of potential between its poles is far less than that between the two coatings of the jar, and consequently the electro-motive force of the latter is much the greater. The Leyden jar discharge is like a small stream of water falling from a great height; the battery current like a large stream flowing over a very gently-inclined bed, and it will be easily understood how much more likely a "shock" is to occur in the former than in the latter case, especially as the resistance of the human body is very high and requires considerable electro-motive force to overcome it.

The physiological effects produced by continuous and alternating currents are also different, and the latter are both more painful and more dangerous than the former. A person accidentally touching a wire, conveying a continuous current of an electro-motive force not high enough to give a shock causing unconsciousness, could release himself at will. In the case of an alternating current he could not do so, and would suffer painful muscular contractions while remaining fixed. Moreover, the human body can bear without danger, continuous currents of a much higher electro-motive force than it can alternating currents.

CHAPTER III

MAGNETIC EFFECTS OF THE CURRENT

First discovery of the deflection of the magnetic needle by the electric current—Ørsted's experiments—Ampère's *memoria technica*—Use of galvanoscope—Of galvanometers—Long and short coil instruments—Astatic galvanometer—Disturbing effect of the earth's magnetism—Compensating magnets—Thomson's mirror galvanometer—Relationship between electric currents and magnetism—Wire conveying current acts as a magnet—Possesses a magnetic field—Magnetic behaviour of a single wire loop—Equivalent to magnetic shell of the same dimensions—Application of Ampère's rule—Experiment with metallic ring attached to floating battery—Modern theory of magnetism—Amperian currents—Production of rotation characteristic of magnetism—Tendency of a single magnet pole and an electric current to revolve round each other—Rotation of liquid conductors under magnetic influence.

THE magnetic effects of the current are of the greatest importance, and so long ago as 1803 it was known that an electric current deflects the magnetic needle from its true position, tending to place it at right angles with the conducting wire, so as to make it lie in fact *across* the current. No use was made of

this discovery, however, nor was it even published, and to Ørsted of Copenhagen belongs the honour of having established the fact by careful experiments and brought it to the notice of the scientific world.

Fig. 18 enables Ørsted's experiments to be under-

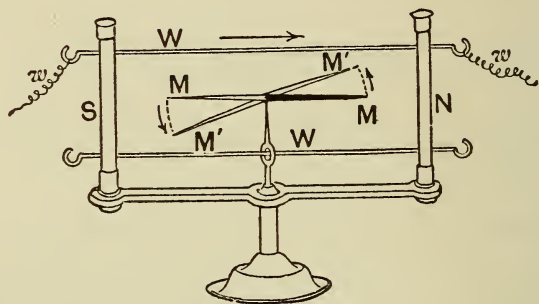


FIG. 18.—W W, wires fixed in the magnetic meridian; M M, magnetic needle lying in its normal position; M' M', the same deflected by a current passing from south to north above it, as indicated by the arrow.

stood. A magnetic needle is placed between two wires lying in the magnetic meridian. One is above and one below the needle, and both are able to be connected with a battery. If a current is made to pass from north to south through the *upper* wire, *i.e.* above the needle, the north-seeking pole of the needle is immediately deflected to the east. If it passes from south to north through the same wire, as in the figure, the deflection of the north-seeking pole is to the west. These deflections are exactly reversed if the current passes through the wire *below* the needle. The north-seeking pole is then deflected to the east

when the current flows from south to north, and to the west when it flows from north to south. Ampère has given a very curious *memoria technica* to facilitate the remembrance of the various deflections. Suppose a man swimming in the conducting wire *with* the current and always turning his face towards the needle,¹ all four deflections will then take place towards his left hand, so that keeping this rule in mind, the following principle will be understood: "In the directive influence of currents on magnets the north-seeking pole is always deflected to the left of the current."

The stronger is the current, the nearer does the deflection of the needle approach to a complete right angle with the conducting wire, but it never entirely reaches this, the directive action of the current being opposed to that of the earth, which tends to keep the needle in the magnetic meridian, so that the position of the needle must always depend on the relative strength of these two forces.

The deflections of the magnetic needle afford a means of indicating the direction and strength of an electric current. An instrument constructed for the former of these two purposes is called a galvanoscope. The simplest of all is made by bending the conducting

¹ To do this when the current passes *below* the needle he would of course have to be lying on his back.

wire into a rectangular form, so that the current passes in one direction below the needle and in the opposite direction above it, thus acting on it with a double strength, because, as we have already seen, a current from north to south below the needle deflects the north-seeking pole in the same direction as a current from south to north above it.

This apparatus even when improved by having a great many turns of wire round the needle instead of one, so as to increase the effect of the current,¹ cannot, however, do more than roughly indicate whether it is strong or weak, or which of two currents is stronger. It cannot correctly measure the strength of a current relatively to other currents. Yet to know this is of the utmost importance in practical work, and for this purpose, therefore, *galvanometers* are employed. It is unnecessary to enter into any detailed explanation of them. The same instrument will not suit all purposes, but every galvanometer must have a magnetic needle surrounded by a coil of carefully-insulated wire. In long coil instruments the wire is turned many, often thousands of times, and is very

¹ Up to a certain limit, the magnetising effect of the current is increased with every extra turn of the wire, but since resistance is also proportionately increased (owing to the greater length of wire which the current has to traverse), it may at length become so high as completely to counteract the strengthening effect of the coils.

fine and thin. These instruments are extremely sensitive and are specially suited for very delicate experiments, and to include in circuits where the resistance is already great. In short coil instruments the wire is thicker and has comparatively but few turns, and these should be used in circuits of low resistance. Some definite controlling force is needful in every galvanometer. It may be that of the earth, or of some fixed permanent magnet. In this case the magnet has to be placed at a considerable distance from the needle, so that the latter may be in a field of practically uniform strength. This condition is always perfectly fulfilled where the controlling force is that of the earth's magnetism; but in the case of very sensitive galvanometers, where it is necessary that the controlling force should be very weak, means often have to be employed to obviate the effect of the earth's magnetism. To fulfil this purpose in some galvanometers, use is made of an *astatic pair* of needles, *i.e.* two needles of equal magnetic strength and size poised carefully one over the other in reversed positions, so that the opposite poles are confronted, each needle being surrounded by a separate coil of wire, the current through one coil being sent in the opposite direction to that through the other. The result of this arrangement is to neutralise the effect of the earth's magnetism

on the needles through their mutual re-action, and a very high degree of sensibility can thus be attained. An astatic galvanometer of very great delicacy is Sir William Thomson's mirror galvanometer, till recently used for signalling through submarine cables. Its general appearance is given in Fig. 19. The readings

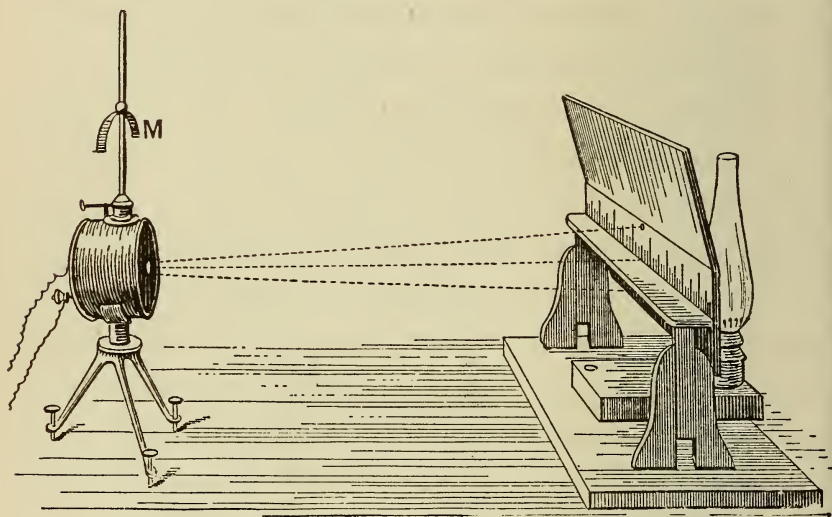


FIG. 19. Thomson's Mirror Galvanometer.

are made by means of a very small light mirror of silvered glass fastened to the magnetic needle. When the instrument is in use, a beam of light is made to fall on the mirror from a lamp, and is reflected with every movement of the needle to a different point on the scale placed opposite, thus indicating exactly the amount of deflection. The curved metallic piece M is a controlling magnet.

In order that a galvanometer should be able to perform its object, viz. afford a means of accurately measuring the strength of currents, it is necessary in every instrument to ascertain the exact deflections of the needle corresponding to definite currents. When this is known, a basis of comparison is provided, because the same instrument under the same conditions will always show the same deflection for the same current. When the experiments and calculations necessary to determine the deflections of the needle of any particular galvanometer for various currents have been gone through, it is said to be *calibrated*. It is calibrated *absolutely* if the actual currents in ampères¹ producing the different deflections are known; and *relatively* if only the connection between these deflections and the relative current-strengths is determined.

The marked effects produced by electric currents on the magnetic needle, give a very clear indication that there is some close relationship between such currents and magnetism. A yet more striking proof of this is, however, afforded by the fact that an electric current itself possesses magnetic properties. The simplest way of proving this is by passing a battery current through a piece of straight copper

¹ The ampère is the unit of current strength, and is defined on p. 203.

wire, and then approaching iron filings to it. The filings at once set themselves at right angles to the wire and cling round it, continuing to do so as long as the current passes; thus showing that the wire has acquired for the time being the power of attracting magnetic substances, if they come within its range of influence. In fact, it produces a magnetic field.

If instead of a straight wire a wire curved into a single loop, as in Fig. 20, be used, and the current



FIG. 20.

passed through that, the magnetic field is now enclosed within the loop and coincides with its edges. In fact, such an

arrangement as this is exactly like a magnetic shell, which we saw (p. 122) was a magnetised sheet of metal, one surface being entirely north-seeking and the other entirely south-seeking. If the observer be so placed as to look down on the loop, and the current be flowing through it from right to left as shown in the figure, *i.e.* in the same direction as the hands of a watch move, the upper surface of the loop and the space enclosed will be south-seeking. Referring to Ampère's rule, we should find that a man swimming with the current and facing towards the centre of the loop would be obliged to keep his

left side *down*, consequently the north-seeking pole of a magnet would turn itself downwards through such a loop. If, however, the current were flowing from left to right, *i.e.* in the opposite direction to that in which the hands of a watch move, the upper surface of the loop and the enclosed space would be north-seeking. In swimming with the current and facing towards the centre, Ampère's man would have to keep his left side *up*. Transforming him into a magnet, we should find the north-seeking pole urged upwards.

A curious and interesting experiment may be made to illustrate these facts by means of De la Rive's floating battery, which consists of a strip of zinc and a strip of copper passed through a large cork and set floating in a vessel containing acidulated water. If the metallic strips be connected by a stout copper ring, and a bar magnet held towards it, the ring will be attracted or repelled according to the pole presented. If the north-seeking pole of the magnet be held towards the south-seeking face of the ring, the latter will be attracted, and will thread itself on to the magnet quite up to the centre. If the south-seeking pole be presented to the south-seeking face of the ring, the latter will be repelled, and if nevertheless forced to pass on to the magnet, will as soon as let go rapidly unthread itself, turn

round so as to present its north-seeking face, and then re-thread itself up to the centre of the magnet as before. This is exactly how a magnetic shell would behave under similar circumstances, supposing that a hole were pierced through its centre to allow of its passing on to the magnet; and in fact every closed voltaic circuit (of which the loop or ring we have been considering is an instance,) is in all respects equivalent to a magnetic shell of the same dimensions. It attracts and repels according to the same laws, and moreover, if placed itself in a magnetic field, it experiences just the same influence as the shell would do. We have therefore here a most striking illustration of the close relationship between magnetism and current electricity, and it will hardly surprise the reader to hear that according to the most modern theory they are in fact identical, only in the latter the flow takes place from one point to another, and may be compared to that of a river, whereas in magnetism the movement is one of rotation like the motion of water in a whirlpool. According to this theory, a magnet (which consists of a number of infinitesimal magnets) has a separate current of electricity circulating round each one of its molecules, and these currents when a perfect state of magnetisation is reached, and all the molecules are set end to end, are parallel to each

other. Without entering into details which might be found tedious and complicated, it is sufficient to state that their effect on external space and objects, is exactly the same as though a current were circulating round the outside of the magnet. This is because only the currents belonging to the surface molecules are free to act externally at all, those in the interior being neutralised by their action on each other. The theory of these molecular currents is due to Ampère, and they are called by his name, *amperian currents*. It is the case that they do satisfactorily explain magnetic phenomena, but it is not probable that they are called into existence by the act of magnetisation. They are most likely already present in magnetic, and in fact in all substances. Magnetisation merely renders their presence sensible externally, by setting them in a parallel direction through altering the position of the molecules. Those substances therefore whose internal structure does not lend itself to such a change, or only with great difficulty, are not capable of magnetisation in the ordinary sense of the term. It must be remembered, however, that when a sufficiently powerful external force is exerted, all substances do feebly show signs either of magnetic or diamagnetic phenomena, and the latter also are explicable by means of Ampère's theory.

That the production of rotation is a characteristic of magnetism can be very easily proved. One simple and striking experiment is described by Dr. Oliver Lodge in his *Modern Views of Electricity*.¹ A long piece of gold thread is suspended in close proximity to an upright bar magnet, and a current passed through the thread. The latter immediately begins to coil itself round the magnet, half of it round the north-seeking pole, and the other half round the south-seeking pole, in such a manner that the two halves form a common spiral. If the gold thread were exchanged for a stiff wire, and a flexible magnet used, the magnet would then coil itself round the wire. In fact, it is proved that a single magnet pole would, if free to move, continually revolve round an electric current, and that an electric current would in the same way revolve round a magnet pole. As we know, however, it is impossible to obtain a magnet with one pole, it must always have two, and therefore a rigid magnet and a rigid conductor cannot possibly show this movement of rotation. All they can accomplish is to place themselves at right angles to each other, as we have seen the magnetic needle invariably tends to do when placed over, under, or near a wire through which an electric current is passing.

¹ P. 135.

Liquid as well as solid conductors can be made to rotate under the influence of magnetism. If a vessel containing acidulated water be placed over a powerful bar magnet and electrodes immersed in it, one at the centre of the vessel and one at the edge, the liquid will begin to rotate, and that so forcibly as very likely to cause it to splash over the sides of the vessel when a current is sent through the liquid.

CHAPTER IV

ELECTRO-MAGNETS

Definition of the term—Discovery of the way of making electro-magnets—Solenoids—Manner of insulating the coils of an electro-magnet—Shapes of electro-magnets—Way of winding the coils of a horseshoe electro-magnet—Position of north-seeking and south-seeking poles—Formation of consequent poles—Core of an electro-magnet takes time to become magnetised—Magnetic strength of electro-magnets—Coils with a number of turns only appropriate in a circuit of high resistance—Kind of metal used for the coils a matter of indifference—Reason of the importance of the iron core.

FROM the observations made at the close of the preceding chapter it will be seen that all magnets may perhaps be *electro-magnets*, because without electricity it is probable that neither magnets nor magnetism would exist. The term is not used, however, in this general sense, but refers exclusively to bars of iron or steel made into magnets by being enclosed in a spiral coil of wire through which an electric current is caused to pass. Steel treated in this way becomes permanently magnetised, but a bar of soft iron only

retains the whole of its magnetism while the current lasts. Consequently, this being a great practical convenience, it is soft iron which is almost invariably used for the "core," as it is called, of electro-magnets. The amount of magnetism which the core retains when the current ceases, is so faint that it seems hardly worth noticing. Nevertheless, as we shall hereafter find, this feeble "residual magnetism" has been made to yield the most important practical results, and it must not therefore go unmentioned.

The principle of electro-magnets was known as far back as 1820, when Arago and Sir Humphry Davy independently discovered that a bar of iron or steel could be magnetised, as shown in Fig. 21, by

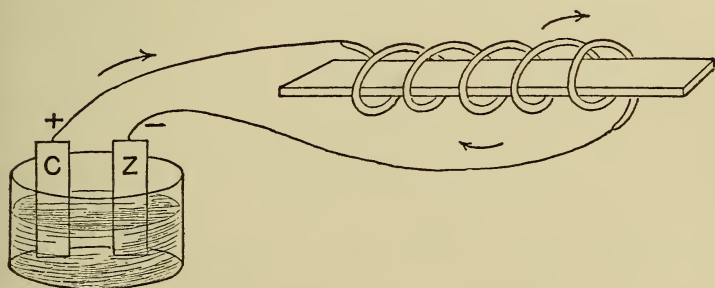


FIG. 21.—Soft iron bar, magnetised by being placed within a wire spiral conveying the current from a single cell.

being enclosed in a wire spiral through which an electric current was caused to circulate. The first practical electro-magnet was, however, made and exhibited by William Sturgeon in 1825, and he is

therefore justly regarded as the inventor of this most useful and important appliance of electro-magnetism. Though a soft iron bar is always used in electro-magnets, it is not indispensable. A wire spiral without a core will also acquire magnetic properties, though never to such an intense degree. It is then called a solenoid, and behaves like a bar magnet, setting itself in the magnetic meridian if freely suspended, and having of course a north-seeking

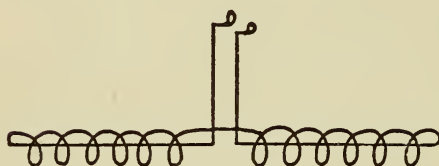


FIG. 22.

and south-seeking pole, which have the power of attracting and repelling other magnetic poles, and of

attracting and being attracted by magnetic substances. Fig. 22 represents a solenoid arranged for suspension.

In electro-magnets care must be taken that each coil of the wire is separated from the next and from the iron core, for if contact takes place at any point, the current passes from one coil to another instead of round each coil, and its effect is thus weakened; for, as has been already stated in a previous chapter, the magnetising effect of the current is increased by increasing the number of coils in the wire, at least up to a certain point.¹ The insulation of the coils from each other and from the core is effected by

¹ See p. 168, note.

covering them with silk or cotton thread, the latter dipped in melted paraffin wax, or with a thin coating of gutta-percha, and they are wrapped as closely round the core as can be managed without weakening the insulation. This is done to avoid the increase in resistance, which the greater length of wire required for wide coils would give rise to. The ends of the core always protrude beyond the coils.

Electro-magnets, like permanent magnets, may be of any shape, but the most usual are the bar and the

horseshoe. Fig. 23 represents the latter, in which two coils of wire are used, leaving the central part of the magnet bare. In order that with this arrangement one pole may be north-seeking and one south-seeking, the

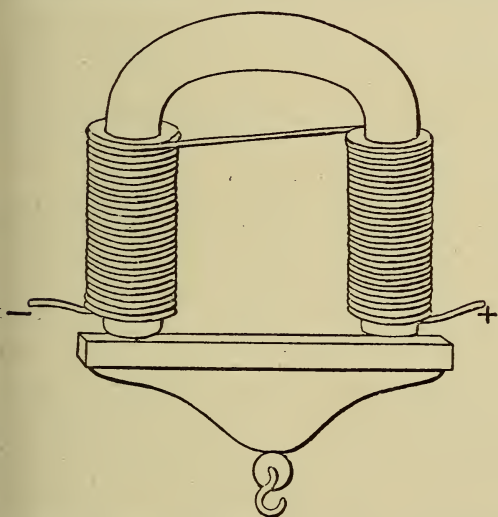


FIG. 23.—Horseshoe Electro-magnet with keeper and hook for suspending weights.

wire must be wound so that if the magnet were straightened out the coils would all follow the same direction. At whichever end the current enters the coils, the north-seeking pole is always that where it

flows round them in the opposite direction to the way in which the hands of a watch move, and the south-seeking pole that at which it flows in the same direction. If the wire is coiled irregularly, at every change of direction a consequent pole is formed, just as happens in the case of an irregularly-magnetised ordinary magnet.

The core of an electro-magnet takes time to become magnetised, partly because an electric current does not (as has already been stated, p. 151) attain to its full strength at once, and partly because of the transient inverse induction currents started in the core itself, when the magnetising current commences to flow through the coils (see p. 195).

Augmenting the strength of the magnetising current, and augmenting the number of convolutions in the coil of an electro-magnet, alike increase the magnetising power of the latter. In fact, for low intensities of magnetisation the amount of magnetism is approximately proportional to the product of the current into the number of convolutions of wire, but after a certain point is reached this ceases to be true, because as the magnetism becomes stronger and stronger it increases less and less slowly with the product, so that beyond a certain point a very large increase in the product is necessary, in order to give rise to a small increase in the magnetism. Never-

theless, as this small increase does take place, it cannot, strictly speaking, be said that such a thing as saturation exists in the case of an electro-magnet. Other considerations besides the intensity of the magnetising force to which it is subjected, affect the amount of magnetism which the core of an electro-magnet can acquire. The quality of iron of which the core is made, its shape, length, and thickness are all of importance. It must be remembered also, that since the resistance encountered by the magnetising current increases with the number of coils, it would be a mistake to include an electro-magnet with a great many coils in a circuit of otherwise low resistance, because the total resistance would be thereby so much increased as to weaken the current. A few turns of stout wire would in this instance answer the purpose better, whereas in a circuit which already has a high resistance an electro-magnet with many coils of fine wire is preferable.

The wire used in the coils need not be of any particular metal. Copper is very often chosen, but for this purpose it has no special merit except its small specific resistance, as neither the material nor the thickness of the wire produces any effect on the strength of the electro-magnet. The important thing is that a sufficient quantity of electricity per second, should be carried sufficiently often round the iron

core, to produce a magnetic field of the required intensity between it and them. For this purpose, when stout wire is used, a few turns will suffice, because in this case a considerable quantity of electricity will be carried round the core of the electro-magnet in one convolution, whereas in the case of fine wire a great many turns are necessary, since one convolution only suffices to carry a small quantity of electricity round the core.

It is of interest to know why the introduction of a soft iron core into a wire spiral should so greatly increase its magnetic strength. The explanation is to be found in the fact of the alteration that takes place in the direction of the lines of force. These in an ordinary steel bar magnet run from end to end, and round outside from one pole to another (see Fig. 11, p. 125). In a solenoid (without a core) very few of them do this, they nearly all remain as closed curves round the wire, each separate coil of which acts like a magnetic shell. When the core is introduced, on account of the high inductive power of iron, most of the lines of force in the solenoid are compelled to alter their direction and follow that of those existing in the iron itself, which run through the length of the iron and back from pole to pole as in the case of the steel magnet already described. Consequently the strength of the poles, being thus reinforced, is very greatly increased.

CHAPTER V

ACTIONS OF CURRENTS UPON CURRENTS—INDUCTION CURRENTS

Mechanical reaction of conductors which are conveying electric currents—Due to attraction and repulsion between the currents—Ampère's laws—Ampère's table—Further laws—Induction of one current by another—Primary and secondary coils—Direct and inverse currents—Induction of currents by magnets—Self-induction—Its effect on the primary current—Contact-breakers—High electro-motive force of induction coils—Ruhmkorff's coil—Sparks from induction coils—The aureole—Effects obtained by means of Geissler's tubes—Effect of a magnet on luminous discharge through rarefied air—Induction currents in solid masses of metal—Lenz's law—Experiment with metal disc suspended between the poles of two electro-magnets—Currents of the higher order.

HITHERTO our observations have been confined to the magnetising effects of an electric current, but another equally important fact demands attention. It is that electric currents act and react on each other, causing movements in the conductors conveying them. These movements are due to the mutual attractions and repulsions between the currents,

for flowing electricity, like electricity at rest, exhibits these phenomena, though they are governed by entirely different laws, first discovered and studied by Ampère.

He found—

I. That currents conveyed by parallel wires attract each other if following the same, and repel each other if following different directions.

II. That currents conveyed by wires which are inclined to each other at any angle, are mutually attracted if both flow towards or both flow from the apex of the angle, and mutually repelled if one flows towards and one from it.

Ampère devised an apparatus known as Ampère's table for observing the actions of currents on each other. It consists of a stand with double supports, upon which wire conductors of different shapes may be suspended in such a way as to allow them to rotate, and at the same time connected to a battery, so that a current may be passed through them and the behaviour of the various portions of wire with regard to each other be observed. By the help of this apparatus Ampère showed that two parts of a circuit in whatever relative position they may be, experience a force tending to set them in such a direction as to enable the currents they convey to flow in the same path; also that a wire doubled

back on itself, so that the current takes a return path close to the one it was following before, does not exert any external force; and further that a zigzag wire exhibits the same magnetic influence over a not very near portion of the circuit as a straight one. Ampère also demonstrated that a conductor never experiences a force tending to move it in the direction of its own length, because the attractions and repulsions between currents always act at right angles to the currents themselves, tending therefore to make them revolve round each other.

Since a mutual action exists between currents and currents and between currents and magnets, it is not surprising that under certain circumstances one current should be able to induce, *i.e.* bring into existence, another, and that magnets should also possess the same power. In their case it is exerted whenever a magnet is moved about in the neighbourhood of a closed circuit, or when the circuit itself is moved in or across a magnetic field. In the case of currents, a current *whose strength is changing* induces a secondary current in any conductor near it; and currents produced in either of these ways are said to be caused by electro-magnetic induction and are called *induction currents*. Their discovery is due to Faraday.

In order to show the induction of currents by currents, two coils of wire are necessary, of which one

is usually large enough to allow of the other being inserted into its hollow. This is merely for convenience sake, however, as the relative size of the two coils is quite immaterial, so far as the generation of induction currents is concerned. The small coil, which is called the *primary* and is made of stoutish wire with few turns, is connected to a battery, and the large coil, in which the wire is fine and often coiled many thousand times, is called the *secondary*,¹ and connected to a long coil galvanometer, as shown in Fig. 24.

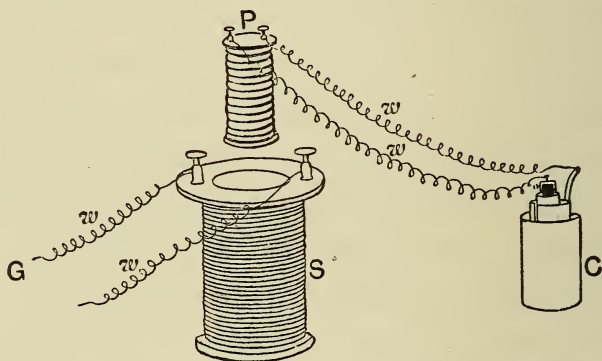


FIG. 24.—P, primary coil ; S, secondary coil ; C, battery cell ; G, position of galvanometer.

When the battery current is passed through the primary coil and the latter inserted into the hollow of the secondary, the galvanometer needle indicates

¹ The result of having stout wire with few turns in the primary, and fine wire with many turns in the secondary coil, is that a large current of low electro-motive force induces a comparatively small current of very high electro-motive force.

a momentary current in the *opposite* direction to that in the primary coil, and the same effect is produced if the current starts in the primary while it is lying in the hollow of the secondary. When the former is withdrawn, or when circuit is broken, while it is lying in the hollow of the secondary, another current is indicated in the latter in the *same* direction as that in the primary. This is called a *direct current*, and the former an *inverse current*. Inverse currents are produced in the secondary coil whenever a current in the primary coil begins, increases in strength, or approaches nearer; direct currents in the secondary coil occur whenever that in the primary ends, decreases in strength, or recedes. Neither inverse nor direct currents ever occur except when a current in the primary starts or stops, or when one of the coils is moved (for moving the secondary nearer to or farther from the primary, produces the same effect as moving the primary itself), and their duration is only momentary.

To show the induction of currents by magnets, it is merely necessary to replace the primary coil of Fig. 24 by a bar magnet. It will be found that whenever the magnet is inserted in, or approached to the hollow of the remaining coil, a current is produced in one direction, and a current in the opposite direction whenever the magnet is taken out or withdrawn to a greater distance.

Besides the induction of one current by another, there is also the induction of a current on itself, called more shortly *self-induction*, to which brief reference was made in a former chapter. By it is really meant, that if two portions of the same circuit are placed side by side, the sudden commencement or cessation of a current in one portion, tends to induce a momentary current in the other, just as if the two portions belonged to separate circuits. Thus suppose we have a wire doubled back on itself, as in Fig. 25,

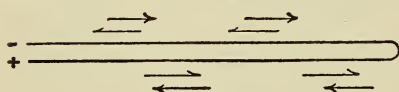


FIG. 25.—Diagram to illustrate Self-induction.

and the primary current flowing in the direction indicated by the single barbed arrows, at the

commencement of such a current there would be a tendency to induce a momentary inverse current flowing in the direction of the double-barbed arrows; and at the cessation of the primary current a tendency to induce a momentary direct current, flowing of course with the single-barbed arrows.¹ This induction has the effect of weakening a current at its start (thus delaying its growing to its full value), and strengthening it at its cessation, which is thus retarded. In fact, since the induction of the current

¹ In a simple circuit, such as that represented in the figure, there would be very little self-induction however, whereas in a circuit coiled many times on itself, there would be a great deal.

in one part of a circuit, takes place on another part of the same circuit across the intervening medium, energy is transferred to the latter while the circuit is closed, and the current remains constant in strength, but is given back to the circuit again to produce the "extra current" on the stoppage of the main current. This is the reason why sparks are obtained on breaking circuit. They are much more brilliant if a coil of many turns be included in the circuit; and if the coil contains a soft iron core, this again increases the sparking power. There are various automatic contrivances called contact-breakers, or interrupters, used for making and breaking circuit with regularity and rapidity, but a detailed description of them is unnecessary for the present purpose.

Induction currents have an enormously high electro-motive force, and very striking effects can consequently be produced by them. These are shown in a marked and powerful way by the induction coil or inductorium, often known under the name of *Ruhmkorff's coil*, as that inventor did much to perfect it. Its most important parts are of course a primary and secondary coil, placed one within the other, and the former connected with a battery and containing a core of straight soft iron wires. Under the coils there is a condenser, which is placed within a flat wooden box and consists of sheets of tinfoil,

separated by sheets of paraffined paper, each alternate piece of tinfoil being electrically connected, so that the whole set forms two series corresponding to the inner and outer coatings of a Leyden jar. A contact-breaker and a commutator or key, whose use is to reverse the direction of the battery current whenever the operator chooses, complete the apparatus. The wires from the primary coil are, as has already been said, connected with the terminals of a battery, and those from the secondary with the condenser, the use of this latter arrangement being that the spark on breaking circuit, may be mitigated by lessening the amount of extra current in the primary coil, some of the electricity flowing into the condenser, instead of to the point where the break is made.

The sparks from an induction coil are extremely powerful, and often attain a great length. From eighteen to twenty inches is not at all unusual with a large instrument, and sparks a metre long have been obtained from some of its most modern forms. These sparks are not exactly the same as those obtained from an electrical machine or a Leyden jar; for besides the spark proper, there is an aureole or glow which surrounds it, and which by the help of a suitable apparatus can be detached from it, thus showing that the two appearances are caused by different discharges. Experiments of various kinds

seem to prove that the sharply-defined spark is analogous to that given by a battery on breaking circuit, and that the aureole is caused by the quiet combination of the opposite kinds of electricity in the same manner as in a galvanic current.¹ The sparks from induction coils are specially suitable for passing through Geissler's tubes, and are very often used for this purpose in preference to those from an electrical machine. Very beautiful luminous effects are then obtained, especially if the tubes are made of uranium glass, or contain a solution of quinine or other "fluorescent" liquid. By fluorescence is meant the property possessed by some substances of changing the colour of rays of light through altering their refrangibility; phosphorescence is the power of becoming self-luminous, a property which can be conferred by the passage of an electric discharge, on that part of a very highly-rarefied gaseous medium near the negative pole. The phenomena of fluorescence and phosphorescence, though somewhat complicated, present points of the highest interest and importance, and a hope seems even to be entertained by some of our leading scientists, that in the course of time discoveries will be made enabling us to produce for ordinary purposes artificial light of this description, which is unaccompanied by heat. In fact, experi-

¹ *Electricity in the Service of Man*, p. 199.

ments in this direction were made by Professors Ayrton and Perry so far back as 1879.

An exceedingly interesting and instructive experiment can be made with a magnet on the luminous discharge in a Geissler's tube, such a discharge possessing the properties of an electric current so that it deflects the magnetic needle, and is itself capable of being acted on by a magnet. Fig. 26 will enable this

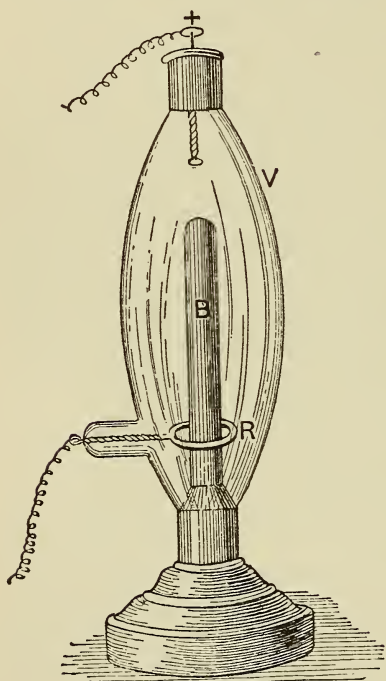


FIG. 26.

experiment to be understood. A soft iron bar B is enclosed in an exhausted glass vessel V, and is surrounded at the lower end by a metallic ring R, and carefully insulated. The terminals of a battery are then connected, one with the upper end of the apparatus and the other with the metal ring, and immediately a sheaf of luminous rays descends towards the ring, surrounding the soft iron bar.

If while the luminous discharge is thus passing, one pole of a magnet be held under the vessel, the iron bar becomes magnetised and the rays of light begin

to revolve round it, thus giving a striking proof both of the rotary tendency of the magnetic forces and of their effect on an electric discharge.

It must not be supposed that induction currents show themselves only in wires. Solid bars or masses of metal of any shape are susceptible of them, and a magnet moved in the neighbourhood of a lump or plate of metal, or the starting or stopping of an electric current near it, induces in it currents which, owing to the resistance they encounter, very rapidly transform their energy into that of heat, and while they last tend to stop the motion of the magnet which gave rise to them. This they do in accordance with a law, known as *Lenz's law* from the name of its formulator, by which all induced currents flow in such a direction that their reaction tends to stop the motion producing them. They thus, in fact, offer a mechanical resistance, which is experienced by any conductor constrained to move across the lines of force in a magnetic field. A curious and striking instance can be given of this by suspending a metal disc by a twisted thread, between the poles of two powerful electro-magnets. While the magnets are inactive the disc revolves rapidly through the untwisting of the thread, but directly the current passes through the coils the disc stops dead, and if forcibly compelled to rotate, grows

rapidly hot, showing how powerful is the resistance encountered.

It has been discovered not only that primary currents give rise to secondary currents, but also that the latter are themselves able to induce currents in closed circuits near them, and not in any way connected with the primary. Thus, suppose that near the secondary coil a third coil is placed, and near this a fourth. When a current commences in the secondary coil an inverse current is induced in the third coil, and a direct current on its cessation. These currents in the third coil give rise in like manner to momentary currents in the fourth coil, and the process may be almost indefinitely repeated. Currents thus induced by the action of that in the secondary coil, are called *currents of the higher order*, and are said to belong to the third, fourth, or fifth order, etc., according to the remoteness of their generation from the secondary.

CHAPTER VI

PRACTICAL UNITS OF MEASUREMENT FOR ELECTRIC CURRENTS

Ways of measuring electric currents—Need of units of measurement—C.G.S. units those on which “absolute” electro-magnetic units are founded—“Practical units” those in common use—Recapitulation of what there is to measure in electric currents—Electro-motive force—Resistance—Strength—Quantity—Names and definitions of practical electro-magnetic units—Other units derived from these to express larger and smaller quantities—Necessity for a unit of capacity—The Farad and Microfarad.

ELECTRIC currents can be measured in various ways—by their influence on the magnetic needle,¹ by the amount of chemical action they give rise to,² and by their heating effects. In order to measure them, however, we must have some scale of measurement to go by. We need, for instance, a definite unit in order to calculate the strength of any given electric current, just as we need a definite unit of time so as to calculate the number of hours in a day or of days in a year.

¹ See chap. iii.

² See chap. ii.

All physical quantities, such as force, volume, velocity, etc., can be expressed in terms of length, mass, and time, and each of these requires a unit of its own on which to base its measurement. In science the almost universally adopted units are—for length the centimetre, for mass the gramme, and for time the second. The centimetre is 0·3937 (considerably less than two-thirds) of an inch, the gramme equals rather more than fifteen grains troy, and the value of the second is practically known to every one. The system of units derived from these as fundamentals is called after their initials the C.G.S. system, and the “absolute” electro-magnetic units, like all absolute derived units (such as those of area, volume, velocity, etc.) belong to it. With the absolute electro-magnetic units such a work as the present need not concern itself. It will suffice to obtain a tolerably clear idea of what are called the *practical units*, which are founded on the absolute units and are those in general use, some of the absolute units being too large and some too small for ordinary purposes.

Before giving a list of these practical units, which are named after various eminent men whose discoveries in electrical science have been specially notable, it will be well to recapitulate exactly what there is to measure in an electric current.

In the first place there is the *electro-motive force* (nearly always indicated by the letters E.M.F.) without which, as has already been stated in Chap. I, p. 143, no current can exist, and on which the power of the current to overcome resistance depends.

Next in order to electro-motive force comes *resistance*, defined in a former chapter as the opposition offered to the passage of electricity through any material substance, and also as the ratio of potential difference to current strength, which in a homogeneous conductor at a given temperature is constant. Resistance of course varies inversely as conductivity. The better the conductor the less the resistance, the worse the conductor the greater the resistance. Every substance has its own specific resistance, just as every substance has its own specific heat.¹ In the case of metals the order of least resistance for electricity is very nearly the same as that for heat, so that silver, which is the best heat conductor, is one of the best electrical conductors also, and mercury one of the worst. In the same substance the resistance varies with difference of temperature; in metals increasing with increase of temperature, in insulators, decreasing. Other causes also affect re-

¹ The specific heat of any substance is the amount of heat required to raise it 1° C. in temperature. The specific resistance is the "resistance in 'absolute' C.G.S. units (*i.e.* in thousands millionths of an ohm) of a centimetre cube of the substance."

sistance ; it increases with the length of wires, and decreases with their thickness. The resistance of a stout metal rod would be nothing in comparison with that of a piece of telegraph wire of the same length, and that of the latter, if only 100 yards long, would be a negligible quantity compared to what it would attain if the wire were 100 miles long.

Resistance is usually measured by comparison with that offered by standard coils of wire whose resistance at a given temperature is known. They are called *resistance coils*, and are wound double, so that their interaction may preserve them from all external electric and magnetic influence, and are usually made of German silver, whose resistance changes little with change of temperature, or of an alloy of silver and platinum, which possesses the same property, or of platinoid. Alloys of metals of course have different resistances from the metals themselves, and even the slightest impurity affects them in this respect.

By the *total resistance* of a circuit is meant that offered by the whole circuit, and by the *internal resistance* that which is encountered in the generating source of the current—as, for instance in the battery cells of a galvanic circuit.

Besides electro-motive force and resistance, there is the *strength of current* to be measured, which is

evidently dependent on them both. Given a high electro-motive force and a low resistance, we shall get a strong current, just as given water running through a pipe at high pressure and with no impediment, we shall get a powerful outflow at the tap. But given the same electro-motive force and a high resistance, we shall get a weak current, just as we should get a feeble outflow of water at the tap in spite of the former being at high pressure, if it had to flow through a partially choked pipe. In fact, strength of current means the quantity of electricity flowing past a given point in a given time, and therefore it is necessary to be able to measure, and to have a unit of measurement for

Quantity of electricity. Electro-motive force is indeed independent of it, but since strength of current is actually the quantity of electricity flowing per second past a given point in a conductor, this strength can be augmented in two ways, either by increasing the electro-motive, *i.e.* the driving, force, or by making the current larger. The pressure of falling water in a pipe is not increased by increasing the size of the pipe, but by increasing the difference of level; yet, other things being equal, the strongest stream of water will issue from the largest pipe simply because it is the largest and holds the most water. In the same

way electro-motive force is not increased by doubling or trebling the quantity of electricity conveyed by a given conductor, but by doubling or trebling the difference of potential between the two ends of that conductor; yet the electro-motive force being the same, a stronger current will flow through a thick than through a thin wire, merely because its thickness allows of the passage of a greater quantity of electricity through the same distance in the same time.

Having thus described what there is to measure in an electric current, the list of units can now be given.

The volt (derived from Volta) is the unit of electro-motive force.¹ It is defined as the difference of potential that must be maintained at the ends of a wire of one ohm resistance, so that a current of one ampère may pass through it.

The ohm is the unit of resistance, and is equivalent to the resistance of a column of mercury one millimetre square and 106 centimetres in length, at a temperature of 0° Centigrade. One mile of ordinary

¹ For practical purposes some particular cell (a standard Daniell's, for example), whose electro-motive force is as nearly as possible one volt, and whose constancy can be depended on, is often used as a standard of electro-motive force; but this does not form the scientific standard of the volt, which is not dependent on the electro-motive force of any cell or chemical combination.

iron telegraph wire has a resistance of from 10 to 20 ohms.

The ampère is the unit of strength of current, and may be defined as a current strong enough to deposit 0.000329 (329-millionths) of a gramme of copper per second on one of the plates of a copper voltameter.

The coulomb is the unit of quantity, and means that quantity flowing in one second past the cross-section of a conductor conveying an ampère.

Since quantities almost indefinitely greater and smaller than those signified by the above units have to be measured by electricians, prefixes are often used expressing one thousand or one million times more, or one-thousandth or one-millionth part, so as to avoid the inconvenience of writing and reading such enormous numbers as would otherwise be necessary. For instance, the currents in ordinary telegraphy are not measured by ampères, but by milli-ampères (or thousandths of an ampère), and the resistance in a good telegraph insulator not by ohms, but by megohms (millions of ohms). The electro-motive force of a lightning flash would be measured, if it could be measured, by mega-volts (millions of volts), and the strength of telephone currents by micro- (millionth) ampères.

It will be understood that though these practical units have been mentioned only with reference to

current measurement, they can also be used for electro-static purposes. The electro-motive force of a Leyden jar (*i.e.* of the difference of potential between its two coatings), or of any condenser, would be measured in volts, just as would be the electro-motive force of a galvanic battery ; and the resistance of any conductor would be expressed in ohms.

It is clear that the electro-static capacity of a conductor, *i.e.* the amount of electricity which, owing to its size, shape, and position, with reference to other conductors, it is capable of accumulating must be of great importance in much practical work, and therefore a unit of capacity needs to be added to those already named. It is called a *farad* (from Faraday); and a condenser, which must naturally be the standard of capacity, has a capacity of one farad, when a potential difference of one volt between its two sets of plates charges each of them with one coulomb. A condenser constructed of tin-foil and paraffined paper like that described in connection with induction coils is most frequently used in practical work, but if made on the scale of one farad as a unit it would be so enormous as to be almost impossible of construction, and quite unmanageable for all ordinary purposes if it were constructed. The practical unit of capacity is therefore in reality the microfarad (one-millionth of a

farad), and condensers are made graduated in microfarads. Even then, for some purposes (such as "duplexing" submarine cables) condensers containing many thousand square feet of tinfoil are necessary.

PART IV

PRACTICAL APPLIANCES OF ELECTRICITY

CHAPTER I

MAGNETO-ELECTRIC AND DYNAMO-ELECTRIC MACHINES AND ELECTRO-MOTORS

Number of practical electrical appliances in modern days—Magneto-electric machines—Pixii's machine—Clarke's machine—Wilde's machine—Siemens' cylindrical armature—Dynamo machines—Their principle—Origin of their name—Now includes magneto-electric machines—Siemens' first self-exciting dynamo—Gramme machine—Principle of Gramme ring—Continuous current machines—Alternate current machines—Various kinds of dynamos—Requisites for a good dynamo—Electro-motors—Their work the converse of that of dynamos—Powerful currents generated by dynamos—Currents of high E.M.F. used for electric lighting—Transformers.

THE practical appliances of electricity in our day are so numerous and so important that it is difficult to know with which to begin. The electric telegraph is

the oldest, and has already attained a familiarity which, in this instance, however, certainly does not breed contempt, for no later invention can surpass or perhaps even equal it, in the magnitude of its effects on the whole human race. Nevertheless, the more recent adoption of electric lighting and electric transmission of power gives them for the moment a greater prominence in the eyes of the world; and since it is impossible to gain any notion of their working principles without some knowledge of what is meant by the three classes of machines whose names head this chapter, it will perhaps be as well to commence with them.

Priority of date belongs to the magneto-electric machines, the first of which was constructed in 1833 by Pixii, a scientific instrument-maker in Paris. His apparatus consisted of a steel horseshoe magnet, which was made to revolve rapidly before two wire bobbins, so that its north-seeking and south-seeking poles passed alternately in front of them. Currents were thus induced in the bobbins which changed direction at every half-revolution of the magnet, but which, owing to the way in which the bobbins were wound,¹ would, if the coils were laid end to end, flow through both in the same direction at the same time. Wires connected the apparatus with an outer circuit, through

¹ See Part III. Chap. iv.

which the currents could be conducted and utilised

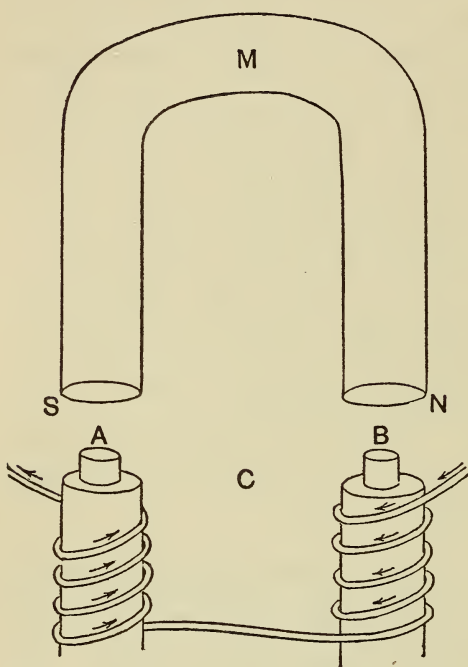


FIG. 27.—To illustrate the principle of Pixii's Machine. M, revolving horse-shoe magnet; A B, soft iron cores surrounded by wire spirals. When S is approaching to and opposite A, and N is approaching to and opposite B, the induced currents flow in the direction indicated by the arrows. When S is approaching to and opposite B, and N is approaching to and opposite A, they flow in the direction opposed to the arrows. In each case there is a momentary cessation of current when one of the magnet poles confronts A and the other B, and a maximum of current when the magnet reaches the position C, so that it is at right angles with the plane of the paper.

for any desired object, and in order to obviate the (for many purposes) inconvenient alternations of the currents, a commutator (current reverser) was introduced, by means of which the currents in the outer circuit could be rendered *continuous*, i.e. obliged to flow always in the same direction. Their extremely rapid succession then enabled them for practical purposes to behave as one uninterrupted current. Fig. 27 enables the principle of Pixii's machine

to be understood. In its construction, however, the magnet is placed below and not above the coils.

The drawback to Pixii's machine lay in the necessity (when a large size was required) of rotating an exceedingly heavy magnet, compelling the expenditure of much mechanical work, for which but a comparatively small return in the shape of electrical energy was made. Clarke and other inventors conceived the idea of making the bobbins revolve before the magnet, instead of the magnet before the bobbins, so that the heaviest part of the apparatus should remain at rest ; and much saving of mechanical power was effected in this way. A small portable form of Clarke's machine is still frequently used for medical purposes.

Magneto-electric machines were next improved by constructing them with electro as well as with permanent magnets. In Wilde's machine, one of the best of the earlier kind, the steel horseshoe magnets are quite small, and used merely to generate currents in a small electro-magnet of cylindrical shape, revolving between their poles, and called an *armature*. The induced currents in this armature are then carried by means of connecting wires through the coils of two large fixed electro-magnets, known as the field magnets, between whose poles another cylindrical armature revolves. The currents thus obtained are exceedingly powerful ; but a great drawback to Wilde's machine exists in the large amount of heat it generates, which not only rapidly weakens

the current, but makes its constancy a matter of impossibility.

The cylindrical armature used in Wilde's and in many magneto-electric and dynamo machines was invented by Dr. Werner Siemens, one of the four celebrated brothers whose scientific discoveries and appliances are so justly famous. Its utility consists

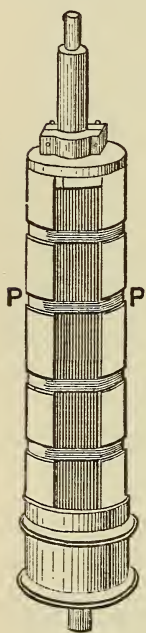


FIG. 28.—
Shuttle-wound
Siemens
Armature.

in the fact, that owing to its shape it is able to revolve in the most powerful part of the magnetic field, *i.e.* exactly between the poles, thus combining high efficiency with great economy of space. The wire in a Siemens armature is wound lengthwise like thread in a shuttle, and is enclosed in an iron sheath open at the sides, as represented in Fig. 28. The poles are not situated at the ends of this armature (or electro-magnet), but on the two faces (P P) of the iron sheath which have not been cut away. At every half-revolution of the armature the polarity is reversed, that which was a north-seeking becoming a south-seeking pole, and *vice versa*.

The principle of the dynamo machines, shortly stated, consists in utilising the residual magnetism left in the soft iron core of an electro-magnet as a

current generator. Nearly all iron retains a faint remnant of magnetism when once it has been highly magnetised; and therefore an electro-magnet, not externally excited, but rotating as an armature between the poles of two much larger electro-magnets, first induces feeble currents in its own coil, and these being transmitted through the coils of the fixed magnets, render them also active, and consequently able in their turn to exalt the magnetism of the rotating armature by their reaction on it. The armature thus reinforced, itself induces and transmits more powerful currents, to be again strengthened in their passage through the fixed or *field magnets* (thus named because their work is to form a powerful magnetic field for the armature to revolve in,) and by this system of continued action and reaction exceedingly strong currents can be obtained in an incredibly short time, and conducted into an outer circuit for use.

The name of dynamos was originally given to machines worked on this principle, because at first sight they appear to owe their electrical energy more directly to the mechanical power expended in rotating the coils, than do the magneto-electric machines. Such is not in reality the case, however. Just as both kinds of machines derive their capability of generating electric currents from electro-magnetic induction, so also both kinds must have mechanical

energy of some description, be it in the form of hand, horse, steam, or water power, expended on them in order to convert it into electrical energy; and it has now become common to include them all under the name of dynamos, distinguishing the two classes as magneto and self-exciting dynamos.

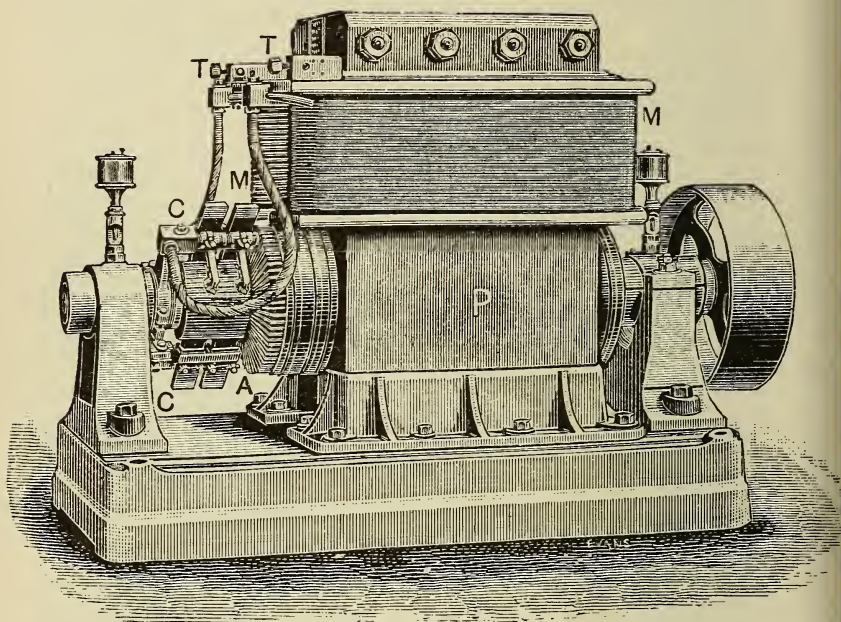


FIG. 29.—Siemens Dynamo (compound-wound). A, armature; M M, field-magnet coils; P, iron pole piece attached to near magnet (that of the far magnet cannot be distinguished); C C, commutator and collecting brushes; T T, terminal binding screws.

The principle of the self-exciting dynamo was simultaneously discovered by Siemens and a partner in the Siemens firm, Hefner von Alteneck, and by Wheatstone and Varley. Since its first

appearance the Siemens machine has undergone various improvements. One of the latest types is represented in Fig. 29. It consists of two powerful flat electro-magnets, between whose poles is a rotating armature, not made on the plan of the original shuttle-wound Siemens armature, but on the same general principle as the Gramme ring, which gives its name to another typical dynamo machine.

The principle of this ring may be broadly understood by reference to Fig. 30.

Suppose N and S to be the poles of a magnet between which a ring of soft iron, wound over with insulated copper wire, is revolving in the direction indicated by the large

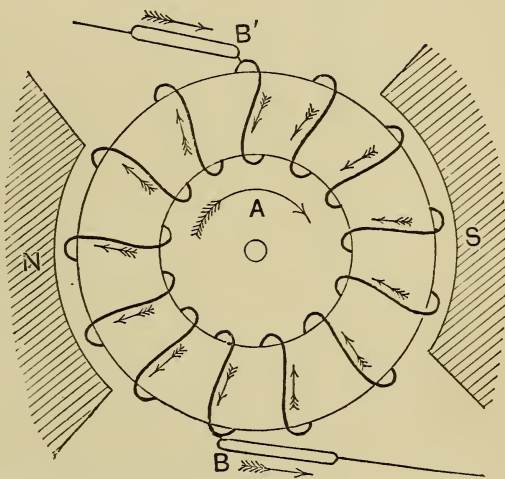


FIG. 30—To illustrate the principle of the Gramme Ring.

inner arrow A. Owing to the action of N and S, magnetism will be induced in the iron ring, and whatever portion of it is for the moment opposite N¹ will possess south-seeking, and that

¹ Not exactly opposite, however. The poles of the rotating ring will in each case be a little further forward in the direction of

opposite S north-seeking magnetism, so that the ring itself acquires poles which remain stationary despite its own movement of rotation. In consequence of this, the currents induced by it in its surrounding coil will be such as to flow always in one direction between B, N, B', and in the opposite direction between B, S, B', as indicated by the small arrows placed near each convolution of the wire. The result of this will be a rise of potential from B past N to B' through one half of the ring, and from B past S to B' through the opposite half of the ring, so that the point of highest potential will always be in that turn of the wire opposite B', and the point of lowest potential in that opposite B. A current will therefore flow through any conductor whose ends are respectively in contact with these points of highest and lowest potential, just as a current will flow through any conductor whose ends are connected to the opposite poles of a galvanic battery. In the actual Gramme machine the ring is not made of one circular bar of soft iron, but of a number of iron wires bent into the required shape, in order to avoid the greater amount of self-induction which would take place in the former case, and which on account of the resistance it entails and the consequent large heat-generation,

rotation than the poles of the field magnets, owing to the iron requiring time to attain its maximum state of magnetisation.

causes a great waste of energy.¹ The armature coils also are not continuous, as in the figure, but divided into sections, which are connected to each other in series, every one being also connected to a separate copper strip forming a segment of the commutator. The necessary contact between the points of highest and lowest potential and the conducting wires is brought about by means of wire brushes, or in large machines by thin copper plates, which are situated at these points, and which as the ring revolves rub against the copper strips already mentioned as forming segments of the commutator. This last is rendered necessary by the fact that a change of direction in the current takes place at B and B' (see the reversed position of the arrows at these points), so that, unless special means were used to prevent it, the current sent through the outer circuit would be *alternating*. Through the action of the commutator, however, it is rendered *continuous*. The Siemens dynamo represented in Fig. 29 is also a continuous-current machine, but a large and important class of dynamos is made to produce alternating currents, and in these (in which of course no commutator is necessary), the direction of the current is constantly reversed, often

¹ No armature cores, in fact, are solid. They are all made of wires or of thin insulated sheets of iron, to reduce as much as possible what are known as the "eddy" or Foucault currents.

many hundred times in a second. Fig. 31 represents a simple form of continuous-current dynamo with a Gramme armature.

It must not be supposed that the dynamos above

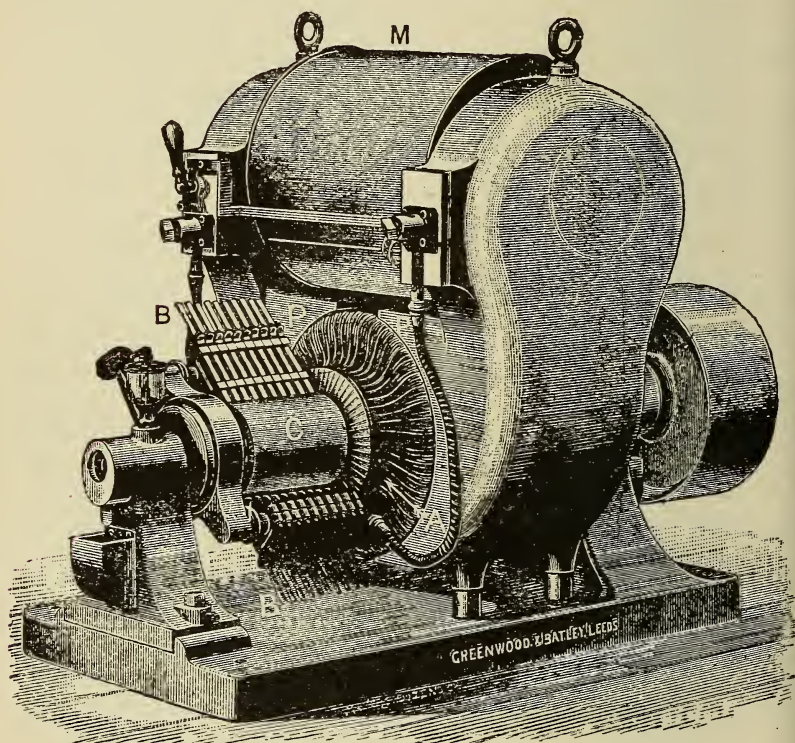


FIG. 31.—Simple form of Dynamo with Gramme Armature. M, coil of field magnet; P P, iron pole pieces; A, armature; C, commutator, B B, collecting brushes.

named are those in exclusive use now. They have been selected for mention partly on account of their historical interest, partly because they are still in wide use and favour. Besides the machines distinguished

by having cylindrical and ring-shaped armatures, many are made whose armatures have the form of a drum, others that of a disc. All these are supposed to possess certain technical advantages, but the main principle of all is the same, and that is the one important thing for the non-technical reader to grasp. Beyond this he will readily understand that what is wanted to make a good dynamo is a powerful magnetic field, a low resistance in the electric circuit, a great facility of magnetisation (high magnetic permeability,) in the armature cores and any magnetic portion of the machine, and as little waste of energy as possible through heating. These objects are accomplished in various ways by various makers, and since it is impossible that all can be equally well attended to in all dynamos, the same kind will not be found equally suited for every purpose. Each special class of dynamo will be best adapted to some special kind of work, and experience alone can assign to each that for which it is most fitted. It may be mentioned, however, that the suitability of dynamos to any particular purpose depends very much on the manner in which the magnet coils are wound. This may be in one of three ways—"series," "shunt," or "compound."

Series-wound dynamos send the whole of their armature current through the field-magnet coils, which

are connected in series with the main circuit. These dynamos are used for arc lighting in series, and sometimes for charging accumulators.

In shunt-wound dynamos the terminals of the field-magnet coils and those of the main circuit are separately connected to the collecting brushes, so that the two circuits are in parallel and not in series. The magnet coils being made of very fine wire, offer a much higher resistance than the main circuit, receiving in consequence but a small proportion of the current, they are therefore said to act as a "shunt." Dynamos of this kind are used for charging accumulators, and in some systems of incandescent lighting.

Compound-wound dynamos have the great advantage of being self-regulating, because a constant potential difference is maintained at their terminals, so that the current in the outer circuit is inversely as the resistance. These dynamos are used for arc and incandescent lighting in parallel, (viz. in systems where the current does not flow from one lamp to another, but to all separately,) and in any case where much regulation is necessary.

The third class of machines to be considered is that of electro-magnetic engines, or as they are usually called *electro-motors*. These, as their name indicates, do mechanical work by means of electricity.

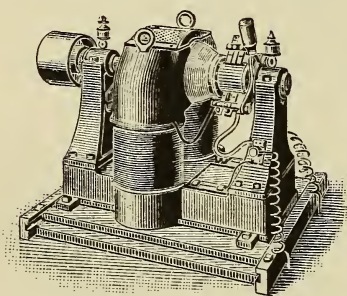
We have seen that dynamos have mechanical work expended on them in order that they may turn it into electrical energy. In electro-motors the process is reversed; they turn electrical into mechanical energy, and that with far less waste than occurs in the analogous case of a steam-engine turning heat into mechanical energy, so that as a motive power electricity might ere this have driven other rivals out of the field, had it not been for the great expense till recently entailed by its use.

The constant and persevering efforts of inventors have therefore been directed as much to reducing the cost, as to improving the construction of dynamos and electro-motors, with how large a measure of success the wide-spread adoption of electric lighting, and to a lesser extent of electric traction, sufficiently prove, while the growing popularity of electrical engineering as a profession, shows with what confidence its future is regarded.

It is not necessary to enter into any detailed description of the construction of electro-motors, as they are so similar to continuous-current dynamo machines, that any one of these can be used as an electro-motor,¹ only if it is so used, it must be driven

¹ Nevertheless it is usually found better in practice to make a machine to be used as an electro-motor specially for that purpose, as slight differences of construction can then be introduced which render it more efficient.

by a current from an external source, not by its own current. The same machine cannot be used at the the same time as a producer of both mechanical and electrical energy ; it will give out either, but not both, and one must first be given to it. Fig. 32 represents a machine constructed purposely to be used as an electro-motor.



MOTOR

FIG. 32.

The currents generated by dynamos may be either of very high electro-motive force or of great strength (many amperes), or both, according to the purpose for which they are required, and the consequent construction of the

machine. For many purposes (such as electric lighting) it is preferable to use currents of a very high electro-motive force. This is much the same as employing a small volume of water at high pressure, instead of a large volume at low pressure ; and, in fact, the term “electric pressure” is very frequently used by engineers. It is important to bear in mind, however, that this is merely a convenient mode of expression, and does not assert (as in the case of water,) an ascertained fact. Currents of high “electric

pressure," *i.e.* of considerable electro-motive force (1000 volts and upwards), are attended with great risk ; for if due precaution is not taken, they are dangerous to life, and should therefore never be carried into private houses, nor is there as a rule any need to do so. For any ordinary illuminating purposes a current of 100 volts is amply sufficient ; and though along the main wires from a central lighting station, it may be necessary to have a current of 2000 volts or more, by means of transformers this can be reduced on entering a house to 100 volts. Transformers are only an adaptation of induction coils in which the usual process is reversed, and instead of a large current of low electro-motive force inducing a small current of high electro-motive force, the exact opposite takes place. Transformers can, however, only be made use of with alternating currents, for it will be remembered that secondary currents never arise except when the strength of the primary is changing. Consequently, if the latter were continuous, secondary currents and any apparatus depending on them would be impossible. Where transformers are used, the electric-lighting circuit of each house is complete in itself, and is not directly connected with the main circuit, the latter merely inducing in the secondary circuits the currents necessary for their purpose.

CHAPTER II

ELECTRIC LIGHTING

Electricity a light-producer—First exhibition of voltaic arc—In what it consists—Size increases with E.M.F. of current—Vividness—Use in lighthouses—Cause of the light—Unequal consumption of the carbons—Consequent unsteadiness of light—Means of rectification—Variety of arc lamps—Illuminative power—Electric candles—Incandescent light—Its principle—Difficulty originally encountered in construction of incandescent lamps—Obviated by improved vacuum—Description of Edison's and Swan's incandescent lamps—Holders—Generation of electric-lighting currents—Central lighting stations—Street illumination—Indoor illumination—Use of accumulators—High-potential currents necessary in main wires—Importance of careful insulation—English mode—American mode—Imperfection of American installations—Safety of electric lighting if properly carried out—Advantages of electric light—Various appliances.

THE electric spark, the electric glow, and the luminous discharge through rarefied gases, all made known (and lightning did so long before them,) that electricity is a light-producer. The possibility of using it for ordinary purposes of illumination was

not understood, however, till the beginning of the present century, when Sir Humphry Davy first exhibited the "voltaic arc" in public at a meeting of the Royal Society in 1810. He employed for the purpose an exceedingly powerful battery of over 2000 elements, and though the beauty and brilliancy of the light were beyond all question, the expense of its production relegated it for a considerable time after this to the region of experiment only. The arc produced by Davy, and of which so much has been heard since, consists of an intensely vivid band of light passing between two carbon pencils, which form part of a powerful voltaic circuit. These pencils, of which an illustration is given in Fig. 33, are first brought into momentary contact and then drawn



FIG. 33.—Carbon Pencils used for the production of the arc light, the positive pencil showing the concave form assumed owing to its more rapid consumption.

a short distance apart. A current of sufficient electro-motive force is able to overleap this gap, but in doing so it has to overcome a very high resistance, and the consequence is an outburst of heat and light of extraordinary intensity. The higher the electro-motive force, the greater may be the distance between the carbon points, and the more vivid of course will be the light. It is too vivid, in fact, for many purposes; it dazzles, and for the

interior of most public buildings, churches, hotels, theatres, etc., as well as for private houses, the incandescent mode of lighting, to be presently described, is far preferable. For open air illumination, however, the arc light presents great advantages, not the least of which is its comparative inexpensiveness; and it is unrivalled in one department of the highest importance, viz. that of lighthouses, where its object is not so much to render other things visible as to be seen itself; it was in fact for them that it was first brought into use. In the search-lights employed for naval and military purposes, its great intensity renders it also specially suitable.

The main cause of the light appears to be the incandescence of minute particles of carbon, which are carried in two incessant streams between the carbon pencils, the principal direction being always from positive to negative. On account of the great affinity of carbon at a high temperature for oxygen, combustion of the pencils takes place even when they are exposed to rarefied air, the positive carbon consuming nearly twice as fast as the negative.¹ Consequently the distance between the two pencils is continually increasing, and unless means of rectification

¹ It must not be supposed, however, that combustion is the cause of the light, as in an ordinary oil or gas lamp, for the arc light can be quite satisfactorily produced in a vacuum or under water.

are used, soon becomes too great to allow the current to overleap it, so that the light, after becoming fainter and fainter, goes out altogether. Numerous ingenious automatic contrivances have been devised to obviate this difficulty, and keep the carbons at an equal distance apart ; and these, combined with the great steadiness of current which is attainable by the use of the modern compound-wound dynamos, have almost completely done away with the flickering and inconstancy of the earlier arc lights. If, therefore, such inconveniences are suffered from in modern days, it is because the installations are in some way less perfect than they could be.

The variety of arc lamps is very great, but their principle having been described, it is needless to go into technical details, which would be wearisome to the general reader. Suffice it to say that the principal aim of inventors is to increase the steadiness of the light by keeping the distance between the pencils as constant as possible, and by using in their construction the purest carbon obtainable. The illuminative power of an arc lamp depends of course on the size of the arc, and this partly on the quantity of current, so that for lamps which are intended to light up a large area, currents of many ampères are needed.

Electric candles, which are a form of arc lamp, must not go unmentioned. The first was the

Jablockoff, so called from the name of its inventor. It consists of two perpendicular rods of carbon, united at the top by a very thin bridge of the same substance, below which they are divided by a layer of some insulating material, usually plaster of Paris. When the current passes, the carbon bridge is rapidly consumed by the intense heat developed, and a voltaic arc takes its place, which melts the insulating material as the carbons gradually burn away. In order that their consumption may be equal, alternating currents are used, so that the same carbon is alternately positive and negative. The Jablockoff candle is equal in illuminative power to ten, twenty, one hundred or more ordinary candles, according to its size. It was at one time in great demand, especially in France, but was never found altogether satisfactory, and has therefore almost fallen into disuse. Later and better forms of electric candle have been devised, using air as the insulating layer, and with other improvements; but they are neither so simple as the regulated arc lamp, nor do they give so high a proportion of light for the current expended on them, and they are therefore not much employed.

On account of the unsteadiness and too great brilliancy of the arc lamps, electric lighting for domestic and most indoor purposes would never have become general had there not existed another and in

this respect more satisfactory method, known as the *incandescent*. In this no gap is formed in the circuit, but it includes substances of very high resistance (such as carbon or platinum), which are raised to a white heat by the passage of the current. Almost every reader is acquainted with the beautiful little lamps known by the names of Swan and Edison, whose light for all ordinary purposes leaves nothing to be desired either in softness or brilliancy, yet hardly ten years have elapsed since their first appearance. The possibility of "incandescent" electric lamps was indeed known long before this, but an insuperable difficulty seemed to lie in the way of their construction, for a material was needed combining two qualifications which had never been found united in the same substance. The first was that it should not, when raised to a high temperature, have an affinity for oxygen; and the second, that under the same circumstances it should not melt. Carbon possessed the latter of these requirements, and platinum the former; but no vacuum had ever been made sufficiently perfect to render carbon incombustible, and platinum could not of course be induced to raise its melting-point, already higher than that of any other metal. The perfecting of the mercurial air-pump at length rendered it possible to produce a degree of exhaustion, in which carbon remained in-

combustible for want of oxygen to combine with, and from that moment the future of the incandescent lamps was secured. Inventors by the score sprang into the field, each with a lamp which some special qualification was supposed to render superior to all others, but the most successful competitors were Swan in England and Edison in America, soon followed by Lane Fox in the former, and Maxim in the latter country.

The principle of the incandescent lamps is the same, whatever differences of detail there may be in their construction. It consists in raising a thin carbon filament, enclosed in a glass vessel exhausted to the pitch of about the millionth of an atmosphere, to a state of incandescence, by the passage through it of an electric current. The carbon filaments are made of different materials by different constructors. Edison uses bamboo fibres, 0·04 inch in diameter and about 5 inches in length; Swan selected cotton thread, which he soaked in sulphuric acid, thus transforming it into a species of parchment; and this preparation is adopted by the Edison-Swan Company. Edison's bamboo fibres are carbonised by being placed in U-shaped moulds and baked in ovens. Swan's thread fibres, after being treated with the sulphuric acid, are bent into the desired form, and enclosed in hermetically-sealed crucibles filled with coal-dust, which are

subjected to the requisite heat. These carbon filaments are fastened to platinum wires, which are fused into exhausted glass vessels, and their free ends connected by appropriate adjustments to the wire conveying the current. In order to ensure equality of resistance, the carbon filaments are made of exactly the same thickness throughout, which is secured by placing the carbon filaments in a hydro-carbon atmosphere, and passing a current through them till they glow. A deposit of carbon on the filaments is the result, the deposit being thickest where the carbons are thinnest and therefore hottest. This operation is called "flashing." At the points of junction with the platinum wires, however, a great increase of thickness is necessary in order to prevent the melting of the platinum by the intense heat developed.¹ Fig. 34 represents an Edison incandescent lamp.

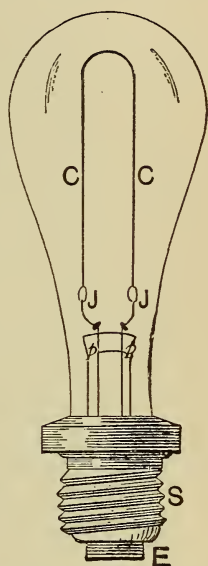


FIG. 34.—Edison's Incandescent Lamp. C C, carbon filament, J J, junctions of the carbon filament with platinum wires; p p, platinum wires by means of which current is conveyed to the carbon filament; S E, metallic screw and end forming the terminals of the lamp, contact being automatically made with the similar parts of the socket into which the lamp is fitted.

¹ It is erroneous to suppose that the electric light is unaccompanied by heat. That of the voltaic arc is the most intense known, and we have seen that even platinum is unable to withstand the high temperature to which the passage of the electric

All incandescent lamps need special holders by whose means the necessary connection with the conducting wire can be set up and maintained.

The currents for electric-lighting purposes are generated by dynamos, which are driven by steam or gas-engines, or when practicable by water-power. For every eight or ten lamps of sixteen candle-power each, current is required which necessitates an expenditure of mechanical work equivalent to one indicated horse-power, so that the dynamos and engines must be in proportion to the amount of lighting to be done and the consequent current needed.

The arc lamps used in street-lighting may be connected to the main circuit either in parallel or in series, according to the system employed. If they are in series, the current passes through each one in succession, and unless special provision is made, they must all be turned on or put out together. In some systems, however, notably the Thomson-Houston, which is the most popular in the United States, the machines are so regulated that though the lamps are in series, any one can be cut out of circuit if desired, by means of a "switch," the amount of current raises it. Nevertheless, on account of the small volume of the arc, and of the incandescent carbon filaments, they give out, though intensely hot themselves, a very minute amount of heat compared to that from gas and candle flames for the same amount of light.

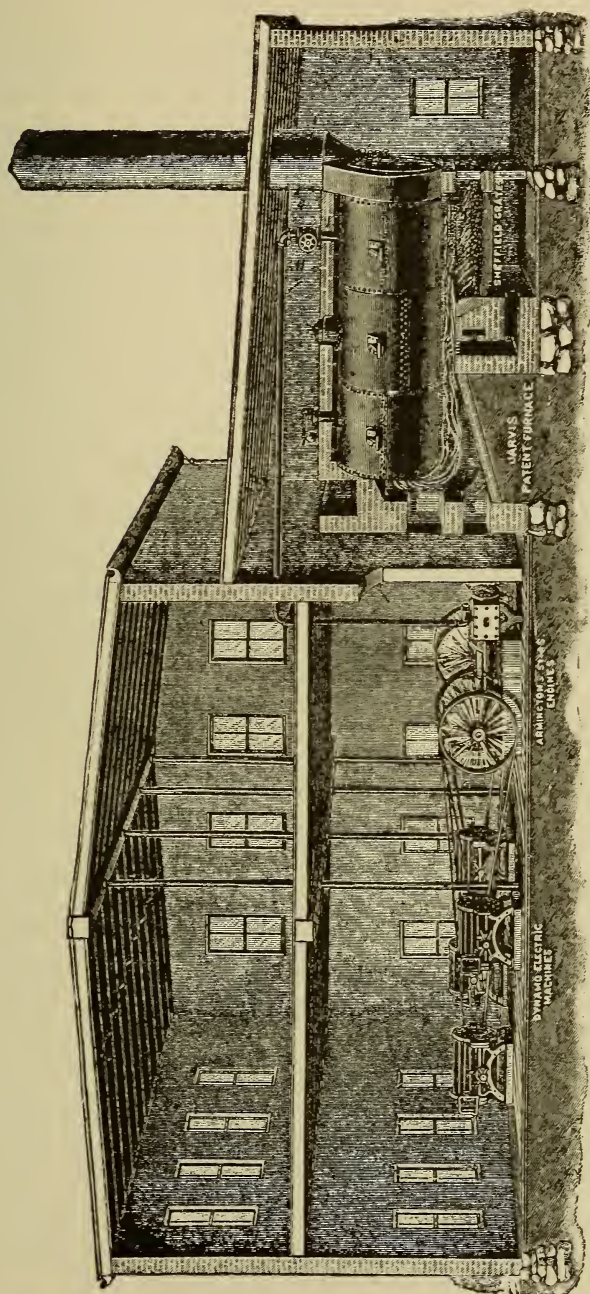


FIG. 35.—Model Electric-Lighting Station on the Thomson-Houston System.

power consumed being in proportion to the number of lamps maintained. Fig. 35 shows a model electric-lighting station on the Thomson-Houston system.

The circuits which supply domestic, and, in fact, all indoor illumination, are often, by means of transformers, or of secondary batteries, kept distinct from the main circuit, the latter being merely used to feed them. In the case of transformers this is done by induction, as was described in Chapter I, the apparatus being carefully enclosed in a locked receptacle, so that no inmate of the house in which it is placed can have access to the dangerous currents. In the case of secondary batteries, or *accumulators*, as they are very frequently called, the charging is done by the main circuit current, from which they are afterwards disconnected and made to do their own work, to be reconnected and recharged when necessary. There are two objections to the use of accumulators, however—their cost is considerable, and they constantly require skilled attention. On this account, when they are used to supply town dwelling-houses, a number are placed together in a sub-lighting station, and each one is connected during the time the current is required to the house which it feeds. When it has to be charged, it is joined in series with the other accumulators belonging to the same group as itself, and this group is then connected to the main circuit

for the requisite number of hours.¹ The advantage of this arrangement is that the dynamos which supply the main currents can be utilised to charge the accumulators during the daytime, and since these then feed their own circuits, the installation at the central station may be much smaller than if it had to provide directly all the current required during the night hours, as is the case when transformers are used. Every lamp for indoor illumination can be, and usually is, supplied with a separate connection to the conducting wire, which can be made or broken at pleasure, so that the lamp may be lighted or put out independently of any other in the same building. A great number also are provided with safety fuses, viz. a piece of wire attached to the lamp, and through which the current must pass. Should the latter attain an undue strength, the fuse melts, the circuit is broken, and the lamp goes out, so that all danger from overheating is obviated.

In order that the distribution of electric energy from the central lighting station may be carried out as economically as possible, currents of very high electro-motive force (usually about 2000 volts,) are

¹ Of course accumulators cannot be charged except by continuous-current dynamos, as the chemical decomposition necessary to the storage of electric energy could not be carried on with alternating currents, which would undo the work as fast as it was accomplished.

conveyed by the main wires, which it is therefore necessary to insulate in the most careful way. In England they are surrounded by layers of insulating material, and buried underground. In America they are often carried overhead, but this system is open to very great objection, as a high wind or heavy fall of snow may break down the wires, and they are then exceedingly dangerous, both on account of the high potential currents they convey, and of their own weight. It is to be observed, that though electric lighting is far more extensively used in America than in England and Europe generally, the technical perfection of the installations is not so good. Insulation is not sufficiently attended to,¹ the neighbourhood of gas-pipes and mains to the wires is not avoided as it should be, so that in case of overheating of the latter, danger of explosion occurs ; and the system of overhead wires, unsightly to the last degree, gives rise to inconvenience and peril, which till lately met with less consideration than should have been the case. In New York, however, a regular rebellion has taken place against the overhead system, the wires have been hewn down in all parts of the city, and their place is being supplied as fast as possible by under-

¹ It is just to say, however, that owing to the much greater dryness of the climate, insulation is far more easily carried out in America than in England, and a system which would be dangerous in the latter country, might be perfectly safe in the former.

ground cables.¹ So many accounts of fatal accidents (numbers of which are untrue,) from electric-lighting currents have been telegraphed across the Atlantic, that timid persons may well shrink from the idea of seeing them come into general use in England. There is no real occasion for alarm, however. If the conducting wires are thoroughly insulated, so as to render the touching and handling of them impossible, very carefully joined where joins are necessary, and thick enough not to be overheated by the strongest current they would ever be called upon to convey, no possible danger can occur. If these precautions are neglected, the consequences may be disastrous, though not more so than if due care is not taken with those equally perilous agents, gas and steam. An electric light installation set up by competent electrical engineers, allowed to provide all those safeguards which they know to be necessary, is perfectly harmless; but if cheapness is made the first desideratum, and bad workmen and bad materials are employed, the result is as unsatisfactory and dangerous, as a similar mode of proceeding would be, if followed by gas and railway companies.

The advantages of the electric over other kinds of artificial light are in many respects very great. In the first place, it is much healthier, for it does not, as

¹ January 1890.

they do, take up oxygen and give out carbonic acid gas. Then, it does not perceptibly raise the temperature of an enclosed space, so that a room or building lighted by it does not become filled with overheated air. Again, owing to its near approach to the composition of sunlight, colours are clearly distinguishable by it, which are confused with one another or altered in hue by gas or candle light; and for the same reason, photographic and other chemical work can be carried on by its means, when they would otherwise be impossible. The electric light is, in fact, particularly rich in chemical rays; and the arc light, owing to the preponderance of violet in its spectrum, gives a cold and rather ghastly appearance to persons and things. This is not the case with the incandescent lamps; and, in fact, when sunlight and any kind of electric light are seen at the same time, the latter is found to have by comparison a reddish hue. The weird effect of the arc light is probably in great part due to our being accustomed to the very red tint of gas; and, of course, where the two illuminants are seen close together, as frequently happens in London, the result is exceedingly unpleasant.

Besides its extensive adoption on land, and for lighthouses, where its superiority over any other kind of illuminant is incalculable, the electric light is also much used now on board ship, as well for ordin-

ary purposes as for signalling; and it is of interest to note that by its means the Suez Canal has been rendered navigable by night, its passage during the hours of darkness being permitted to all vessels carrying electric search-lights, arranged according to the regulations laid down by the Canal Company. The use of electric search-lights on board warships has already been referred to, and their importance can hardly be overestimated, now it is acknowledged that nets are of little if any protection against torpedoes, so that the only safety from these formidable engines of destruction, lies in being aware of their approach. This can only be ensured at night, by throwing powerful streams of light in every direction from which danger is to be apprehended, and the intensity of the arc light makes it specially suitable for this purpose, rendering the detection of torpedo-boats a matter of comparative ease.

Among the minor uses to which the electric light has been put, the production of very beautiful scenic effects in theatres may be mentioned; and it has even been made to contribute to the personal adornment of the actors. "Electric hairpins" are described in *Electricity in the Service of Man*.¹ They are simply miniature glow lamps arranged so as to simulate gems of various colours, and supplied with the neces-

¹ P. 562.

sary current by a tiny battery enclosed in a gutta-percha box, small enough to be concealed in the hair or head-dress. Another very ingenious contrivance is mentioned in the same work, and consists of an apparatus enabling a faint light like that of the Will-o'-the-wisp to play about the heads of those wearing it. The frequent variations of intensity which are necessary in theatrical lights render indispensable, contrivances enabling any particular lamp, or whole series of lamps, to be put in and out of circuit as desired; and, in fact, such arrangements are required in all indoor illumination, as the number of lamps in use in any building is constantly altering. If many lamps are put out of circuit at the same time, it is necessary, unless compound-wound, *i.e.* constant potential-difference, dynamos are supplying the current, to increase the resistance encountered, as the current would otherwise be too powerful for the remaining lamps. To accomplish this, arrangements are made by which resistance-boards or coils can be included or cut out of circuit at will. The latter are merely wire coils usually made of German silver; the former consist of a number of parallel carbon rods fixed on a wooden board, any or all of which can be included in circuit as desired.

A very curious appliance of the electric light is mentioned in *The Electrician* for 10th January 1890

viz. its being used to lure fishes and submarine animals into a trap employed in the deep-sea investigations undertaken by the Prince of Monaco. The light and the battery supplying it were placed in a wire trap, and in order to keep the box in which the battery was enclosed from being crushed by the enormous pressure of water, it was connected with an air balloon in such a way that air could pass from one to the other. As the pressure on the balloon increased in its descent through the water, air was forced from it into the box, thus providing the interior of the latter with an equal and contrary pressure to that exerted on its exterior, the balloon itself gradually diminishing in size till it was reduced to a fraction of its original volume, and expanding again when the apparatus was raised and the pressure of water decreased. The experiment was so successful, that the Prince hopes on his next expedition to obtain photographs of the ocean bed by means of the electric light.

For purposes of electric lighting and transmission of power, it is obviously necessary that both supplier and consumer should be able to gauge, with fair exactitude, what amount of electric energy is used ; but the measurement cannot be accomplished in so simple and certain a way as the measurement of gas consumption for instance. The latter depends

upon quantity only, but the measurement of electrical energy depends upon the electro-motive force (or pressure), as well as on the strength of current. If the former were to fall below its right value, the consumer would not be getting his due proportion of energy, though the current strength might be fully maintained. The meter employed, therefore, ought to be a *volt-meter* or measurer of electro-motive force, as well as an ampère or *am-meter*, measurer of current strength. It is not easy to combine these two requisites in a simple and efficient form, and many inventors have employed their ingenuity in this direction, without as yet obtaining a perfectly satisfactory result. The best appears to be given by the clock-meter of Professors Ayrton and Perry, whose most important constituent is a good clock, the works of which are electrically connected to the wires conveying current to and from the house, in such a way as to be affected both by its pressure and strength. The clock consequently loses in exact proportion to the amount of energy consumed. If, however, a constant electric pressure between the house mains can be secured, it is sufficient to measure only the quantity of current that passes.

CHAPTER III

TRANSMISSION OF POWER BY ELECTRICITY

Definition of power—Units of power—Various agents for the transmission of power—Its importance—Loss incurred—Advantages of electricity as a transmitter of power—Its probable universal adoption—Requisites for the transmission of power by electricity—Electric railways—Telpherage—Attempts to utilise electricity for road traffic—Other applications—Electric launches.

By the term “power” engineers understand the rate of doing work. The transmission of power therefore means not simply the transmission of work, but of a given amount of work in a given time. The ordinary unit of work in England is the *foot pound*, viz. the amount of work done in raising one pound to the height of one foot. For engineering purposes horse-power, which is equivalent to 33,000 foot pounds per minute, is often used as the unit of power; and in electrical engineering the unit of power is the Watt, which equals $44\frac{1}{4}$ foot pounds

per minute, so that 746 Watts are equivalent to one horse-power.¹

Power may be transmitted by various agents. We may pull a handle connected to a bell wire, and thus ring a bell in a distant room ; the wire is here the transmitter of power. Or there may be no bell wire, but by pulling the handle we may cause the compression or rarefaction of air in a tube, at the other end of which the bell will ring. In this case the transmitter of power is the air. Or the bell may be an "electric bell," and by the pressure of our hand on a button in the wall we may start an electric current, by means of which the ringing is accomplished ; electricity then being the transmitter of power. It is the transmitter only, however, not the source. That, in each of the three cases mentioned, is the human hand, whose action in pulling or pressing the bell handle, originates the power transmitted by the wire, the air, or the electric current.

Even from such a trivial example as the ringing of a bell, it is easy to see what importance attaches to the transmission of power, and what saving of time and labour it may enable us to effect. Because the mechanical action of pulling or pressing a bell

¹ Electrically defined, the Watt is the power developed in a circuit through which a current of one ampère is flowing, and which has a potential difference of one volt between its ends.

handle, can be transmitted to a distance, a slight exertion and a small bell will suffice ; but if we could only ring the bell at the spot where we ourselves might be, a much larger bell and far greater exertion would be necessary, in order to attract the attention of those at a distance.

In all transmission of power some loss occurs. We never get back exactly the amount of power originally expended, and where the distance is great the loss is often very considerable. It is less where electricity is employed, than in any other case, however, and consequently now that dynamos and electro-motors are so much less costly of construction than they were a few years ago, electricity bids fair to become the cheapest, as well as the most rapid, cleanest, and most easily controlled transmitter of power known. It has not, indeed, yet been applied to great distances and large power ; but whatever initial difficulties there may be in thus utilising it, they are not of such a formidable nature as to prevent, or even long retard, its widespread adoption ; and not scientists and electrical engineers only, but the foremost statesman in England¹ has ventured to look forward to the time when noisy and crowded factories will be abolished, and each workman sup-

¹ Lord Salisbury in his speech at the First Dinner of the Institute of Electrical Engineers.

plied at his own house with the power necessary for his work, distributed from a central station as electric-lighting currents now are. In fact, with very little increase of cost and material, the same station would serve both purposes. The currents are not wanted for lighting during the daytime; and though, where accumulators are used, they must be charged, this would not occupy all the dynamos at a central station, nor any of them during a whole day, so that, at no very distant future, we may contemplate the establishment of centres which shall supply each household with light during the hours of darkness, and with power during the day. This system is already extensively adopted in America, to supply workshops where only small power is required, such as those of tailors, shoemakers, watchmakers, etc., but it has not yet been attempted on a large scale.

The requisites for electrical transmission of power are—

1. Mechanical power of some kind to drive the dynamos.¹
2. The dynamos or current-generators themselves.

¹ It is not intended to state that the transmission of power by electricity, can only take place by means of currents generated by dynamos. Batteries may be used; but for reasons already pointed out they are unsuitable, except when (as in telegraphy) the power to be transmitted is very small.

3. An electro-motor or motors, placed where the supply of power is required.

4. An electrical connection between the dynamos and the electro-motors, unless accumulators are used, when such connection is of course unnecessary, and the dynamos are employed for charging.

The driving of the dynamos is generally accomplished either by water-power or steam. Wherever the former is available, it is the best and most economical to use, and the continual regret of electrical engineers is the amount of energy running to waste in our streams and rivers, their dream for the future being that as electrical transmission of power becomes better understood, and more easily available over long distances, the water-power of every country may be found sufficient for its needs. Dynamos and electro-motors have been described in a previous chapter, and with regard to the connection between the two, it varies according to the nature of the work to be performed, and with other local and technical causes.

The most important use to which electricity as a motive-power has been put, is that of traction. Electric railways, or, more correctly speaking, tramways, as they are used only over short distances and for light traffic, are becoming well known, though not yet common. The motors are usually placed under the floor of the cars, and are supplied with current either

through the rails on which the cars run, or by separate underground conductors, or by overhead conductors as in Fig. 36; or they may be driven by accumulators, which in some ways simplifies matters, as the rails

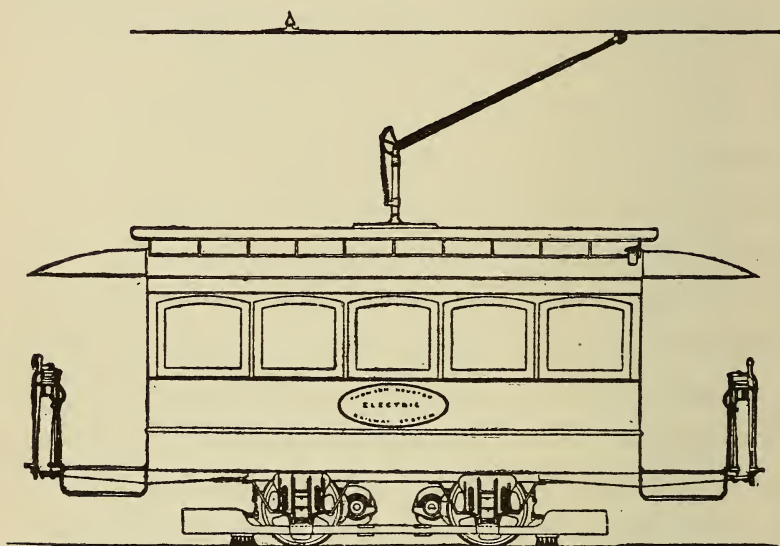


FIG. 36.—Electric Tramcar supplied with current by overhead conductors.

need not then be insulated, and each car can be independent of its fellows. In other respects this system has disadvantages; the weight of the accumulators, which of course must be carried by the cars, being one, and the double transformation of energy they entail being another, as more waste is thereby necessitated.¹

¹ Where accumulators are employed, mechanical energy (that used to turn the dynamo armatures,) must first be converted into electrical energy, then the latter changed in the accumulator to stored-up chemical energy, which on being liberated is transformed once more into electrical energy, and then through the electro-

The telpherage system, formerly used for the transport of goods only, but now beginning to be employed for passengers also, is specially suitable and economical for hilly country, and was introduced by Professors Ayrton and Perry, and the late Professor Fleeming Jenkin. In this system the traffic is carried on overhead, the conductors and trucks being suspended from poles erected about fifty yards apart. The conductors sometimes consist of two steel cables fixed one above the other, the trucks being suspended between them, and the upper cable bearing most of the weight. More usually, however, there is only one steel cable (as in the passenger telpher line at the Edinburgh Exhibition,) by which the whole weight is supported. The trucks are provided with wheels through which, as they run along the conductors, the necessary current is supplied.

Attempts have been made to utilise electricity for ordinary street traffic, as well as for railways. In this case the motors which propel the vehicles are of course driven by accumulators, and success has been attained for short distances and light weights;¹ motor back into mechanical energy. Where the dynamos supply the motors directly, two transformations only take place, from mechanical into electrical energy in the dynamo, and from electrical into mechanical in the motor.

¹ An electric dogcart, made for the Sultan of Turkey in 1888, gave its imperial owner so much satisfaction that he has since ordered another.

but for long distances, difficulties occur through the necessity of exchanging the exhausted accumulators for fresh ones; and when the cart or carriage is heavy, it is impossible to stop it with the rapidity often necessary in crowded streets. This difficulty arises from the increase of weight occasioned by the use of large accumulators, which gives too great a momentum to the vehicle.

Electricity has been made useful for locomotion in mines, for boring rocks, for lifts, for cranes, for brakes, (the Westinghouse brake being familiar, at least by name, to all readers,) and for driving machinery in factories.

Electrically-propelled ships have not been attempted on a large scale, but many electric launches are made, and found to answer exceedingly well. Their chief inconvenience lies in the fact that owing to their motors being driven by accumulators, they cannot go far from the charging station, unless indeed (as has been done on the Thames,) sub-stations are placed at intervals on the line of route, so that exhausted accumulators can be replaced by fresh ones when necessary. The most recent application of electricity to naval purposes, has been independently made by the French and Belgians, in submarine electric launches or torpedo boats, recalling on a small scale the marvellous

vessel in Jules Verne's *Twenty Thousand Leagues under the Sea*.

The various uses to which electricity as a motive power has been put, have now been enumerated, but there is one to which neither it nor any of its rivals has yet been successfully applied, but which nevertheless we can hardly help regarding as probably one of its important functions in the future—this is aërial navigation. If our descendants are to travel in balloons, it will certainly be through the agency of electricity ; and as the various electrical engines become more and more perfected, we can hardly doubt that in time a sufficiently light means of storing electric energy will be devised to make that dream of past ages—a flying machine—an actual reality.

CHAPTER IV

THE ELECTRIC TELEGRAPH

Early suggestions for using electricity and magnetism as a means of communication—Volta's and Ørsted's discoveries the foundation of modern telegraphy—Number of inventors who have contributed to its perfection—Wheatstone and Cooke's telegraph—Discovery of the "earth-circuit"—Introduction of the "translation" system—Recording and non-recording instruments—Morse's services to telegraphy—His embosser and ink-writer—The Morse key—Speed of transmission of messages—Hughes printing telegraph—The Morse sounder—Submarine signalling—The syphon recorder—Manner of conveying and insulating overland wires—Submarine cables—Duplex and quadruplex telegraphy—Telegraphic currents generated by batteries.

It seems that the first really practical suggestion for using electricity as a means of communication, was made by the anonymous author of a letter to the *Scots Magazine* in 1753. The suggested apparatus, though cumbrous and complicated according to modern ideas, was very ingenious, but there is no record of its having been actually used. The writer, and such of his readers as took any interest in the subject, were

doubtless of opinion that at any rate the idea was an entirely novel one, but in this they were to some extent mistaken. Though nothing was known about "current" electricity until the end of the eighteenth century, there had been vague ideas long before then, that magnetism might be in some way utilised for purposes of communication. About 1750 a certain Joseph Glanvil, rector of Bath, who we are informed was a "learned writer upon abstruse and mystical subjects," wrote as follows in a treatise entitled "The Vanity of Dogmatising," and in which he speaks of "supposed impossibilities which may not be so."

"That men should confer at very distant removes by an extemporary intercourse is a reputed impossibility; but there are yet some hints in natural operations that give us probability that 'tis feasible, and may be compassed without unwarrantable assistance from demoniack correspondence. That a couple of needles equally touched by the same magnet, being set in two dials exactly proportioned to each other, and circumscribed by the letters of the alphabet, may effect this 'magnale' (*i.e.* important result), hath considerable authorities to avouch it. The manner of it is thus represented. Let the friends that would communicate take each a dial, and having appointed a time for their sympathetic conference, let one move his impregnate needle to any letter in the

alphabet, and its affected fellow will precisely respect the same. So that would I know what my friend would acquaint me with, 'tis but observing the letters that are pointed at by my needle, and in their order transcribing them from their sympathised index as its motion directs, and I may be assured that my friend described the same with his, and that the words on my paper are of his inditing. Now though there will be some ill contrivance in a circumstance of this invention, in that the thus impregnate needles will not move to, but avert from each other (as ingenious Dr. Browne hath observed), yet this cannot prejudice the main design of this way of secret conveyance; since it is but treading counter to the magnetic informer, and noting the letter which is most distant in the abecederian circle, from that which the needle turns to, and the case is not altered. Now, though this desirable effect possibly may not yet answer the expectations of inquisitive experiment, yet 'tis no despicable item, that by some other such way of magnetic efficiency it may hereafter with success be attempted, when magical history shall be enlarged by riper inspections; and 'tis not unlikely but that present discoveries might be improved to the performance."¹

¹ The above curious passage is quoted from a letter by the Rev. Canon Jackson of Leigh-de-la-Mere, Chippenham, the well-known antiquarian, to the *Bath Chronicle* in October 1890.

Could Joseph Glanvil's spirit revisit us now, he would see his expectations more than fulfilled, though it has not been by "riper inspections of magical history," but of natural science that the "reputed impossibility" has become possible. Forty years after the treatise "On the Vanity of Dogmatising" saw the light Volta had made his first battery, and twenty years later still, came the announcement of Ørsted's famous experiments on the action of electric currents on the magnetic needle. These two discoveries are the foundation-stones of our modern system of telegraphy, which would be impossible without a steady current, as distinguished from the momentary rush of a discharge, and to which the deflections of the magnetic needle, under the influence of electric currents, contributed a code of signals far superior to any which had previously been attempted with electricity.

So many scientific inventors have aided in bringing the electric telegraph to its present degree of perfection, that it would be impossible in the short compass of a chapter of the present volume, even to name them all. The first really workable telegraph introduced into England, was that of Wheatstone and Cooke, who at first employed five needles and as many wires to transmit their signals, but soon finding the cost and inconvenience of this method rendered its general adoption impracticable, they reduced the

number of needles to two and finally to one, whose deflections to the right and left were so combined, as to represent all the letters of the alphabet. In all the earlier telegraphic circuits it was considered necessary to have a return wire, but in 1838 Steinheil discovered that this could be dispensed with, and that if the two ends of the conducting wire were connected to earth, one at the sending the other at the receiving station, the earth itself would play the part of the return wire. This discovery of the "earth circuit" was of the greatest practical importance, owing to the reduction in cost which it brought about.

Another very important improvement in the construction of electric telegraphs, is the system of "translation" which was introduced by an Englishman, Edward Davy. The principle consists simply in cutting up one long circuit into a number of short ones, which can be automatically connected whenever a signal is transmitted. The advantage of this system is that even on a long circuit a weak current may be employed, as it will only have a comparatively short distance to traverse before its work is taken up by another.

The telegraphic instruments in modern use may be divided into two classes, recording and non-recording. To the former (whose signals are merely momentary and leave no after traces), belong the

needle and dial telegraphs and the sounders. To the latter belong the embossers, ink-writers, and type-writers. In international telegraphy and in the English Post-Office, Morse's instruments, of which some are recording and some non-recording, are almost exclusively used, and a slight description of them will therefore be given. Their inventor, Morse, who received considerable sums of money from various nations, in recognition of his services to international telegraphy, was an American, and his first experiments in the direction in which he afterwards became so famous, were made as early as 1834, when he had already twice visited Europe. He laboured at first under the disadvantage of very inadequate electrical knowledge, and indeed his mind was originally turned to what became his life-work, by the accidental acquaintance made on one of his return voyages to America, with a fellow-traveller, Professor Jackson of Boston, who was engaged on electrical experiments. At a later period Morse was indebted to his subsequent partner, Leonard Gale, for various suggestions as to the chemical part of his work.

Morse's embossing instrument leaves a permanent record of the message sent, by indentations on a slip of paper. These are made by means of a small electro-magnet with a movable armature, to which is attached a hard pointed piece of metal. Whenever a

current passes through the instrument the armature and stylus are drawn forward, and the latter brought into contact with a slip of paper, unrolled and passed on by clockwork. When the current is interrupted, the armature and stylus return to their former position, to be again drawn forward as soon as a current is set going. In this way a series of scratches is made on the paper, the marks being longer or shorter according to the length of contact, and divided by spaces varying with the time of interruption of the current. The short marks are known as dots, and the longer ones as dashes, and by suitable combinations of them all the letters of the alphabet, the numerals, punctuations, and various signs are expressed in a system of signals, known as the Morse code, which is now almost universally adopted in Europe and America.¹ Morse's ink-writer, which is in most general use, is on the same plan as the embosser, but the place of the stylus is taken by a small disc kept constantly wetted with ink, by means of a suitable mechanical arrangement, so that ink-marks instead of scratches are impressed on the paper.

The incessant interruptions of current necessary in the Morse, and in all telegraphic instruments, are brought about by means of a commutator or key, by

¹ The Morse code is used in the needle telegraphs also, an inflection to the left representing a dot, and one to the right a dash.

which the operator closes and opens circuit at will. The Morse key is simply a brass lever kept in position by a spring S, as shown in Fig. 37. When the

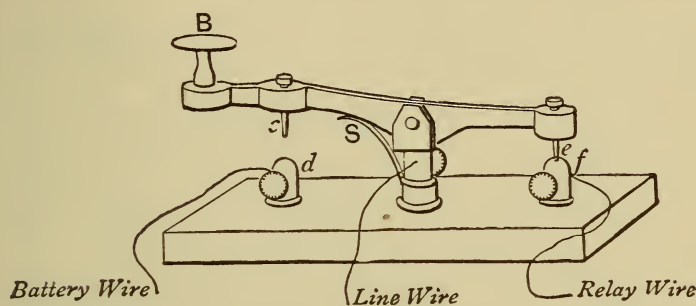


FIG. 37.—The Morse Key.

operator presses down the button B, he causes *c d* to come into contact, and by their means sends a current from the battery into the line wire. When B is not pressed down, *e f* are in contact as in the figure, and a current coming along the line passes round the relay electro-magnet (see Fig. 38) and works the relay tongue (*a*). This closes the circuit of a local battery, which sends a sufficiently strong current round the electro-magnets of the receiving instrument to pull down the lever of the embosser or ink-writer, an operation requiring too much force to be accomplished by the weak current which comes along the line. Polarised relays, *i.e.* relays in which the core of the electro-magnet is formed of a steel magnet, whose poles are not reversed by change of direction in the current, are almost always used.

It is evident that the speed of transmission of messages must depend to a great extent on the number of currents required to form the different

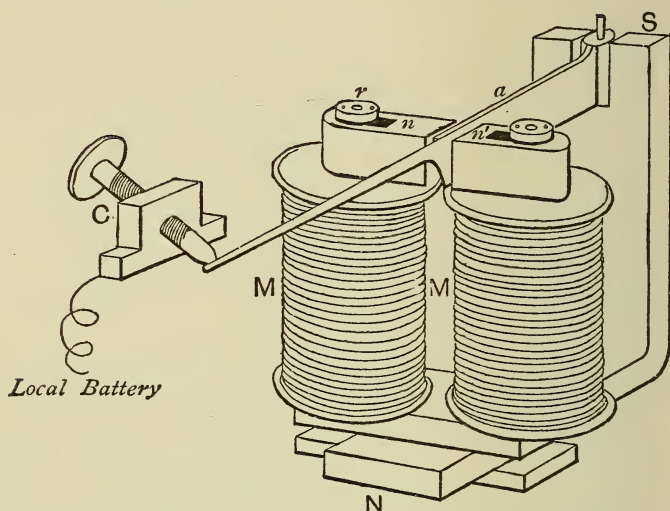


FIG. 38.—Polarised Relay. S N, permanent steel magnet whose north-seeking pole is bifurcated, its branches making the core of the electro-magnet M M, and terminating in the pieces *n* and *n'*, between which works the soft-iron armature or tongue *a*; connection is made with the local battery by means of the contact-piece C whenever a current passes through the coils M M.

letters. In the Morse system about three currents are wanted on an average for each letter. Inventors have therefore endeavoured to construct apparatus in which fewer should be necessary. The most successful of these is Hughes' printing telegraph, which requires only one current for each letter, and which can also print its messages (transmitted in a third of the time occupied by a Morse instrument), in Roman characters. The apparatus is, however,

so complicated that it can only be entrusted to a thoroughly trained and skilled operator; its use is therefore confined to very important telegraphic lines.

The Morse sounder (for which the Morse key is used as a commutator,) is a non-recording instrument, and its signals appeal to the ear instead of to the eye. Its simplest form is one in which a small electro-magnet is supplied with an armature in the form of a lever, the free end of which works between two stops, and taps against one when the current starts, and against the other when it ceases. The intervals between the taps are made longer or shorter according to whether a dash or a dot is to be represented, a short pause corresponding to a dot and a longer one to a dash. It is evident that in this system mistakes are more liable to be made in a message than where reference can be had to recorded signs. Nevertheless, with skilled operators errors very rarely occur, and the greater rapidity with which transcription can take place offers an advantage which in America, at all events, outweighs other considerations, for the sounder is used almost to the exclusion of any other instrument. It is also widely adopted in India.

Submarine signalling, where the distance is great, requires special and very delicate instruments, the currents being too weak to work satisfactorily with

any ordinary apparatus.¹ For a considerable time Sir William Thomson's mirror galvanometer (described in Chapter iii of Part III, p. 174,) was almost exclusively used, but owing to the great fatigue to the eyes incurred by watching the movements of the little spot of light for a long time together, this instrument has now been to a great extent superseded for signalling purposes, by another invention from the same high quarter, the syphon recorder, which by means of a flat coil of wire in circuit with the line, and suspended between two powerful electromagnets, communicates motions to a very fine glass syphon, dipping into an insulated metal ink-vessel, and having its other end adjusted over a paper strip. When a message is to be recorded the vessel of ink is connected with a charged conductor, and the result is to force the drops of ink on to the paper, unrolled by clockwork, as in the Morse instruments. The mechanism is so arranged that when a current is passing, the point of the syphon moves alternately to one side and the other of the centre of the paper, and thus two lines of ink-spots are made, one of which corresponds to the dots, and the other to the dashes of the Morse code.

¹ The current given out by the Atlantic cable, when twenty-five words per minute are being transmitted, is one-millionth of an ampère.

It is hardly necessary to describe the mode in which ordinary overland telegraph wires are conveyed from place to place. We are but too familiar with the gaunt wooden posts, and the wire lines suspended from them which make our railroads even more hideous than they would otherwise be. The wires thus employed are made of galvanised iron (iron coated with zinc,) and every post carries insulating supports through which the wires pass. In England, and Europe generally, overhead wires are replaced in large towns by an underground system, in which a number of wires are enclosed in iron or earthenware pipes and buried in the soil. These wires are made of copper, and each one is insulated by a gutta-percha covering. But for the greater cost and small mechanical strength of copper wires, they would always be preferable to iron for telegraphic purposes, owing to their much lower specific resistance, and their greater power of withstanding exposure to the weather. If the wires break, come into contact with other wires, or with conductors connected to the earth, there ensue total or partial interruptions of the currents they convey, technically known as "faults." Various means are taken to prevent these and to ensure their speedy remedy when they do occur. The most important precautions are the thorough insulation of the wires,

the frequent introduction of "testing-boxes" along the circuit, which enable the real position of the fault to be speedily discovered, and (in the case of overhead wires,) the metallic connection of each one of the insulating supports with the earth. This obviates the danger of one wire leaking into another (which might otherwise frequently occur in wet weather), by supplying an easier and more direct path to the earth for the leaking current. These earth connections of the insulators also serve the important purpose of lightning conductors, which are indispensable both along the line and at the signal stations, as without them the lightning discharge might travel along the wires, not only interrupting the messages, but destroying the telegraphic instruments, and injuring or even killing the operators. Such accidents have more than once happened. In wires carried underground, another difficulty has to be contended against, viz. the taking up by the wires of a static charge of opposite sign to that of the surrounding earth, which in fact acts as one coating, while the wires act as the other, of a Leyden jar. This condition of things weakens the current and prevents rapid signalling; but it is not often that underground wires are of sufficient length for the currents they convey to suffer seriously from this cause. It is far otherwise with the submarine cables,

some of which (as those which cross the Atlantic,) are 2000 miles or more long. Special means have then to be taken to obviate the delay, and even failure of transmission. The most effectual seems to be employing alternate positive and negative currents, as then each one as it passes through the cable counteracts the effect of its predecessor. The use of the exceedingly delicate recording instruments already referred to, is another important consideration, as a much weaker current is then able to suffice.

Submarine cables, especially when of great length, require to be exceedingly strong, in order to withstand the enormous pressure of water they encounter when being lowered, the buffeting of the waves near shore, and the friction against the uneven and often rocky bed of the ocean. The Atlantic cables, of which there are now nine, are made of seven strands of copper wire, covered with four layers of gutta-percha encased in tanned hemp. Over this are twisted stout iron wires also covered with hemp. Fig. 39 gives a

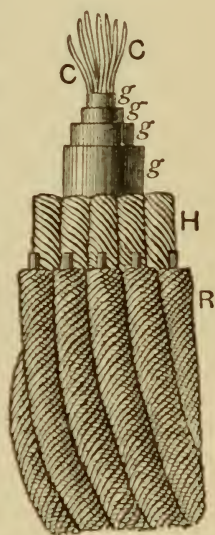


FIG. 39.—Section of an Atlantic Cable. R, outer casing of tanned hemp ropes enclosing stout iron wires; H, inner casing of tanned hemp ropes surrounding the four gutta-percha layers *g g*; C C, strand of copper wire (untwisted), forming the conductor by means of which the messages are transmitted.

representation of a portion of an Atlantic cable showing the different layers.

One of the most important improvements in modern telegraphy is the introduction of the duplex system, which enables two messages to be sent in opposite directions along the same wire at the same time. In order to do this, it is necessary that when a signal is transmitted from one station to another, the receiving instrument at the sending station should not be affected, but remain free to indicate any message travelling to it from the opposite direction. This end is attained in various ways, and not only has duplex telegraphy come into constant use, but still further developments have taken place, so that a single wire is now able to convey four or more messages at the same time. Quadruplex telegraphy, however, entails the necessity for two sending and two receiving instruments at each station.

Currents of low electro-motive force are the most suitable in telegraphy, as they are then less liable to leak, and the mechanical work required of them is very slight. They are consequently almost exclusively generated by galvanic batteries. A form of Daniell's cell has been chiefly adopted in England, but the Leclanché is also excellent for telegraphic purposes and is coming widely into use.

This slight and inadequate sketch can give but a faint idea of the enormous proportions to which the science of telegraphy, for it is a science in itself, has now attained, but indeed no assertion of the fact is necessary, for we are brought face to face with it every day and almost every hour of our lives. Those multitudinous wires spreading over our continents and spanning our widest oceans, may well strike us with a feeling somewhat akin to awe, for they are the nerves of the world, connecting its centres of intellectual, political, and commercial activity with the remotest individual life, and flashing interchanges of thought between nation and nation.

CHAPTER V

THE TELEPHONE

Novelty of the idea of transmitting spoken words—Reis's telephone—Graham Bell's telephone—Weakening of the sound in transmission—Invention of the microphone—Its principle—Combination with the telephone—Transmitting and receiving instruments used in England—Feebleness of telephone currents—The Telephone Exchange system—Transmission of concerted music—Telephone wires—Necessity of guarding against induction—Means employed—Effect of earth currents and atmospheric electrical disturbances—Sensitiveness of telephone made useful as a test for weak currents—The microphone employed for medical purposes—The phonograph.

As we have seen in the preceding chapter, the possibility of communicating at a distance by means of magnetic signs, though it had never been successfully attempted when the electric telegraph was invented, was no new idea. The transmission of spoken words, however, had not even been thought of, and its accomplishment came with almost as much surprise on scientific men as on the general public; but during the last twenty-five years we have become so

used to talking with persons many miles away from us, that the thing has almost ceased to excite wonder, and in many of our large towns telephonic communication is becoming as important and common as that by telegraph.

The first telephone was invented by a German, Reis, in 1860. It could not, however, transmit articulate speech, but only musical notes, whose vibrations are so much less complicated than those of the human voice in speaking, that they are far more easily reproduced.¹ One of the earliest forms of Reis's telephone consisted of a conical tube of wood, across the narrow opening of which was stretched an exceedingly fine membrane. One end of a narrow strip of platinum foil rested on the centre of this membrane, while the other was attached to a binding screw. A second strip of platinum attached to another binding screw, and having a small pointed projection for making contact, was so adjusted, that one end just touched that portion of the first platinum strip which rested on the membrane. The binding screws were connected to a battery, and to a wire through which the sounds were

¹ The possibility of reproducing sounds at a distance, depends on the fact that each one is caused by certain definite and periodic vibrations. If these can be transmitted in their entirety to another place, the sound must naturally be reproduced at that place.

to be transmitted. When a musical note was sounded close to the membrane, the latter was set in oscillation, and at each complete vibration (*i.e.* movement *to and fro*), made and broke circuit once, by means of the motion imparted to the platinum strips. This interrupted current was transmitted through the line wire to the receiving instrument, which consisted of a violin, on whose bridge was fastened an upright knitting-needle, enclosed in a coil of fine silk-covered copper wire. The alternate magnetisation and demagnetisation of the knitting-needle as the current flowed or ceased in the coil, produced the sound which always occurs when iron is thus treated; but since the number of times the needle was magnetised and demagnetised, exactly corresponded to the number of vibrations communicated by the musical note to the membrane whose motions started and interrupted the current, those vibrations were again exactly reproduced in the motion transmitted by the needle to the air, and the note was sounded once more. Reis afterwards made many improvements in his telephone, but he never succeeded in getting it to speak. In the first place, no instrument depending entirely on interrupted currents would be delicate enough for this purpose,¹

¹ The experiments of Graham Bell, whose telephone is described in the text, led him to distinguish between three kinds of currents,

and in the second, though he constructed very elaborate mouthpieces for his transmitters, he paid but little attention to those of his receivers, though it seems obvious enough now that they were by far the most important, being directly concerned in the reproduction of the sounds.

The first speaking telephone was invented by Professor Graham Bell, a naturalised American citizen, about four years after the appearance of Reis's telephone. It consisted of two exactly similar instruments, one used as a transmitter and the other as a receiver, and its principle is easily understood by reference to Fig. 40. A steel magnet M is terminated at the end near the mouthpiece P by a piece of soft iron surrounded by a coil of very fine copper wire, covered with silk, and having its terminals permanently connected to the binding screws S S, one of which is connected to the line wire and the other to earth. Over the coil is a thin disc of soft iron D, tightly fastened at the edges, but with its centre free and nearly touching

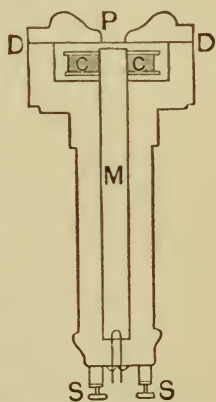


FIG. 40.—Section of Graham Bell's Telephone.

intermittent (when the current is periodically interrupted), *pulsating* (when its strength rises and falls suddenly), *undulating* (when its strength rises and falls gradually), and it is these last which are principally concerned in the transmission of human speech.

the end of the magnet. Above the disc is the mouthpiece P spoken into in the case of the transmitter, and held to the ear in the case of the receiver. When the transmitter is used, the pressure of air against the thin iron diaphragm is altered with every inflection of the speaker's voice, and it is consequently set in vibration, making (to the eye,) imperceptible movements backwards and forwards in front of the wire coil, and thus starting alternate currents in it which are transmitted through the line wire to the coil of the receiving instrument, strengthening or weakening the magnetism of its core according to their direction. The result of this is to cause the second diaphragm to be attracted more or less strongly with every changing current, and so to vibrate in exactly the same manner as the diaphragm of the transmitter, imparting a similar motion to the air, and thus reproducing the sounds which originally started the currents. In fact, there is here a transformation of energy, precisely analogous to that which takes place between a dynamo and an electro-motor, only instead of mechanical motion being changed into electric currents by the dynamo and back again by the motor, we have sonorous vibrations transformed into electric currents in the telephonic transmitter, and restored to their original form in the receiver. The analogy can be

pursued further. Just as the same amount of work is not given out by the electro-motor that was expended on the dynamo, so with the telephone also, loss occurs in the process of transmission, and the voice given out by Graham Bell's original apparatus was much weaker than that which had spoken in the first instance. For this reason the instrument was not altogether satisfactory, though it could and did transmit perfectly intelligible messages over a considerable distance.

What was wanted in order to enable the telephone to attain the great practical importance which it has now reached, was the discovery of some means by which the weakening of the sounds transmitted could be obviated. Hughes, whose printing telegraph was mentioned in the preceding chapter, accomplished this by his invention of the microphone, some form of which is now invariably used as transmitter in telephonic circuits. The action of the microphone depends on the principle, that if the pressure between conductors in contact is altered, there is an alteration in the electrical resistance of the circuit of which they form a part; so that if the pressure is lessened the resistance is increased and the current becomes weaker, while increase of pressure entails diminution of resistance and the current becomes stronger. Carbon is the substance best

adapted to contacts of varying resistance, and carbon is consequently used in nearly all microphones, of which Fig. 41 represents a simple but very effective kind.

When this instrument is placed in circuit with a

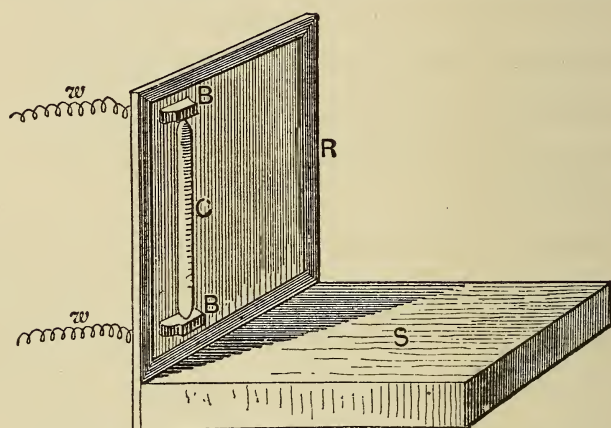


FIG. 41.—Microphone. C, carbon pencil; B B, carbon blocks with slight depressions (not represented) on which the ends of the pencil loosely rest; R, resonant board; S, wooden slab; *w w*, connection to battery.

telephone and used as a transmitter, the sounds emitted by the former are often very much louder than the original ones, simply because the varying pressure between the carbon pencil and its supports, so affects the currents as greatly to strengthen the vibrations to which they give rise in the receiving diaphragm. In fact, not only are audible sounds made louder, but sounds quite inaudible to the unaided ear are rendered perfectly distinct; the walk of a fly even, over the soundboard of the microphone, being clearly

distinguished in the telephonic receiver, and words spoken at some yards distance from the former, being distinctly heard in the latter.

The instruments most used in England are the "Blake" transmitter, a form of microphone, and the "Bell receiver, which is simply a Graham Bell telephone as described above. Besides a battery and the transmitting and receiving instruments, it is found advisable to include an induction coil in the circuit, the battery and primary coil being in connection with the transmitter, and the secondary coil with the receiver.¹

Telephonic currents are calculated to be millions of times weaker than those used in ordinary telegraphy, and their alternations are so excessively rapid, that there is no instrument delicate enough to make their presence known by optical signs. Their ready detection by the ear is consequently a striking proof of its extreme sensitiveness to any periodic movement, however slight.

The Telephone Exchange system, owing to which telephonic communication in our large towns has reached its present state of perfection, must not be passed over in silence. In principle it much

¹ In the original Graham Bell telephone no battery was needed, the currents being generated in the transmitter by the movements of the diaphragm in front of the magnet; but where a microphone is used a separate generator is required.

resembles an electric-lighting installation. Just as the latter has its central and sub-stations, so the Telephone Exchange has its central and local exchanges connected by means of "trunk" wires. Each local exchange is connected to one or more others, and every subscriber has a private wire by means of which he can communicate with the local exchange to which he is attached. He is provided in his own house or office with a telephonic apparatus, consisting of a transmitter, a receiver, a battery, and a small magneto machine for making call signals, and a number by which he is to be known at the exchange is assigned to him. When he wishes to speak with another subscriber, he signals to his own local exchange, and if the second subscriber belongs to it also, they are put in immediate communication by having their respective telephonic circuits connected to each other. If the second subscriber belongs to a different local exchange, the signal is sent on to that, and communication is then opened between the persons who wish to converse by means of the two exchanges. If, however, the subscribers belong to local exchanges which are not connected with each other, the Central Exchange, with which all are connected, is signalled, and communication is set up through that. The institutor of this exceedingly practical and well-devised system was the

father-in-law of Professor Graham Bell, Mr. Hubbard, who seems to have seen from the first, the great possibilities of his son-in-law's invention.

The telephone is now often used for the transmission of music as well as of speech, whole concerts being made audible at distant places. Special arrangements are of course necessary in this case, as many considerations have to be attended to. It is necessary that the instrumental and vocal performances should preserve their due proportion of sound with regard to each other, that all extraneous sounds such as persons walking about the stage of the concert room, etc., should be excluded, and that the position of the singers should not interfere with the effect produced. All these difficulties have been successfully surmounted, even that of sufficiently insulating the transmitting microphones from any sounds but the music. To effect this they are placed on thick layers of lead covered with gutta-percha.¹

¹ It is exceedingly difficult to insulate sound, and no substance so perfect for this purpose as gutta-percha is for insulating electricity has yet been discovered. Professor Hughes, the inventor of the microphone, says, "The question of insulation has now become one of necessity, as the microphone has opened to us a world of sounds, of the existence of which we were unaware. If we can insulate the instrument so as to direct its powers on any single object, as on a moving fly, it will be possible to investigate that object undisturbed by the pandemonium of sounds which at present the microphone reveals where we thought complete silence prevailed."—Quoted from *Electricity in the Service of Man*, p. 723.

It is most common to employ overhead wires for telephonic purposes, but in some places (as in Paris) underground cables are used. In any case, it is most important if the telephone wires are near others employed for different electrical work—such as telegraphy—to guard against the effects of induction, as the extreme sensitiveness of the telephone renders it specially liable to be interfered with by them,¹ and to have its true message interrupted or spoiled by sounds which have nothing whatever to do with it. A return wire (instead of the earth circuit), is generally found an efficient protection ; but other means are also used for underground wires, one of which is to sheath the telephone wire in an iron covering, so that induction shall take place in this, and leave the wire itself unaffected.² “Earth currents” often produce disturbances in the telephone, causing a peculiar crackling noise, and thunderstorms give rise to very powerful effects. A flash of lightning too distant to be seen, may produce a sound in the telephone, and it is stated that this often occurs before the flash, showing that inductive action must have taken place previous to the discharge.

¹ It is, indeed, through using the telephone as a testing instrument that the fact before suspected has been proved, that any wire near another wire conveying an electric current has an induced current given rise to in it, however short the wires may be.

² It is equally necessary to guard telephone wires from induction by each other, or else messages sent by one travel along the others also, and the words are reproduced at several receivers.

The extreme sensitiveness of the telephone renders it very useful as a testing instrument for weak currents, there being apparently none so feeble that it will not give evidence of their presence; and a special apparatus devised by Professor Hughes, and called the *induction balance*, has been made of great use for the instantaneous testing of metals. It consists of a battery connected to two small primary coils, near each of which is a secondary coil in circuit with a telephone. The arrangements are so made that the currents in the secondary coils are opposite, and exactly equal in strength. Now, two equal and opposite currents destroy each other, so while this condition of things obtains, there is no sound in the telephone, but if one or the other current is ever so slightly increased or diminished in strength, the equilibrium of the balance is disturbed and an electromotive force arises, sufficient to cause a sound in the telephone. The testing of metals is thus carried out. Within each secondary coil is a box containing the specimens to be tested. If they are exactly similar, as for instance two genuine sovereigns would be, no sound is heard in the telephone; but if a difference exists, such as that between a true and false coin, the currents in the secondary coils no longer balance each other, and the telephone emits its warning note.

The microphone has been made very serviceable for medical purposes, and special instruments such as the "miophone" and the "sphygmophone" have been constructed for the examination of the muscles, pulse, veins, arteries, etc., in the human body; and there is no doubt that in time the use of such apparatus will become widely extended.

During the last two years public attention has been much drawn to an invention as surprising and ingenious as that of the telephone, viz. the *phonograph*, and though this instrument is not electrical, it can hardly be passed over in silence, for it was devised and perfected by the great American inventor, to whom we owe so many marvels of applied electrical science; and, moreover, in its latest form the phonograph is driven by small electro-motors, deriving the necessary current from a battery of one or two cells. Electricity has therefore been utilised for it, and moreover, it is stated that Edison is endeavouring to combine the phonograph with the telephone in such a way, that even if no listener is at hand the latter can record its message to be heard when convenient. The work of the phonograph is to store spoken words or any desired sound, and to reproduce them when required. In order to effect this, it is necessary that the sonorous vibrations should make a permanent impression on some suitable substance, and

that this impression should be able to give rise to exactly similar vibrations to those which produced it.

Edison's first phonograph consisted of a brass cylinder, turned by a handle, and on which was cut a spiral groove. A piece of tinfoil was wrapped round the cylinder, and over it was fastened a metal diaphragm, having a metal point attached which rested on the tinfoil. Above the diaphragm was a mouthpiece. When the latter was spoken into, the diaphragm was caused to vibrate, and the cylinder being set in revolution at the same time, the metal point made a series of indentations, the depth of each varying with the strength of the vibration causing it; and this, of course, with the various inflections of the voice. These indentations were the record of the spoken words, and when the latter had to be reproduced a mouthpiece was held over a diaphragm exactly similar to the first, but placed with its attached point on the opposite side of the cylinder, which was revolved as nearly as possible at the same rate as when the record was being made. The second diaphragm was thus thrown into vibration exactly corresponding to that of the first, and the spoken words were reproduced. The sound was, however, thin and metallic, the record on the tinfoil wore out after being used a few times, and the instrument would only give satisfactory results in the hands

of an expert, and not always then. Though interesting and ingenious, it was therefore only a scientific toy. In Edison's perfected phonograph, first exhibited in England in 1888, the brass cylinder of the original instrument is replaced by one of solid wax, and the metal point by a cutting style, so that, instead of a series of indentations, a wavy line is made in the spiral groove. The metallic twang and unevenness of speech is thus done away with, and the true timbre, and all the inflections of the voice are reproduced ; moreover, the record on wax is far more durable than that on the tinfoil, for one of these waxen cylinders may be used more than a thousand times, and yet show no sign of deterioration. Impressions can be taken of them to any number desired, so that without speaking the record more than once, it can be indefinitely multiplied, and since the mechanism for revolving the cylinders, etc., is exactly the same in every instrument, they can be sent about by post to any person who possesses a phonograph, and be made to reproduce their recorded speech or music for his benefit. Usually it is necessary to insert acoustic tubes in the ears in order to hear the phonograph, but the necessity for this can be obviated by placing a suitable funnel on the instrument, and its sounds are then made audible to a roomful of people at once. Distinctness is,

however, lost by this process. The only obstacle which seems to lie in the way of the adoption of the phonograph for everyday purposes, is the fact that the cylinders require careful adjustment when put into the instrument, and therefore a certain amount of skill is necessary. It is hardly probable, however, that so slight a reason will long keep the use of the phonograph in abeyance. The graphophone which, though improved from Edison's original phonograph, was not perfected by himself, requires less skill in the adjustment of the cylinders. On the other hand, its intonation is not so perfect.

CHAPTER VI

ELECTRO-METALLURGY AND MISCELLANEOUS APPLIANCES OF ELECTRICITY

Electro-plating—Dynamoes used to generate the necessary currents—Quantity of current the important consideration—The “bath”—Anode must be made of the same metal which is to be deposited—Electrotyping—Method of obtaining facsimiles of medals—Of wood-engravings—Reduction of metals from their ores—Fusion of metals with high melting-points—Welding—Medical appliances of electricity—Sewer purification—Firing of submarine mines—Electric bells—Alarums—Clocks—Conjectured possibility of transmitting vision.

It has already been stated that an electric current is able to separate metals from their solutions, and that the liberated metallic atoms are always deposited at the negative electrode, or kathode. This property of the electric current has been made of great practical use in the now familiar process of electro-plating, under which comprehensive term is usually included the covering of any metal with a coating of another, whether the latter be precious or not.

Formerly batteries were used to generate the required currents, but it is now found better and more convenient to employ continuous-current dynamos for this purpose. They are, however, of a different kind from those used for electric lighting and transmission of power, in both of which a current of high electromotive force is required. This is not necessary in the case of the deposition of metals. Quantity of current is there the important consideration, and the dynamos are constructed accordingly. The method employed is as follows. The object to be plated is made the negative electrode, and immersed in an electrolytic cell, known for this purpose as a "*bath*," and filled with an acid solution containing a salt of the metal, say silver, to be deposited. The positive electrode is made in this case of a plate of pure silver, and immersed in the same solution. The current is then passed through the bath, the electrolytic liquid is decomposed, oxygen is liberated at the anode, and silver deposited on the kathode, *i.e.* on the object to be plated, and the process is continued until a coating of silver of sufficient thickness is obtained. If the plating is to be of gold or copper, exactly the same method is followed, only the solution is different, and in each case must contain a salt of the metal to be deposited. The object of making the anode of the same metal, is that by its gradually dissolving in

the acid it may replace that which is being deposited on the kathode. Otherwise all the metal in the solution would be used up, and the process come to an end before the requisite thickness of coating had been obtained.

Electrotyping is another most important branch of electro-metallurgy. In this industry electrolytic deposition is used to obtain facsimiles of medals, wood-engravings, ordinary printing type, and even daguerreotypes. To obtain the facsimile of a medal, a cast of the latter is first taken in some suitable substance, which if non-conducting is rubbed over with metallic powder to make it conduct. It is then immersed in a "bath," containing a solution of copper, and forms the negative electrode. The positive electrode consists of a solid bar or plate of copper. The current is then started and continued till a thick coating of copper is deposited on the mould, from which it can afterwards be easily detached. For facsimiles of wood-engraving, a mould of gutta-percha is first taken from the block itself, and then subjected to electrolytic deposition of copper for twenty-four hours. The engraving is then found to be reproduced on a very thin plate of copper, which is strengthened by having melted type-metal run in at the back. From the "electrotype" many thousand impressions can be taken, and it is chiefly owing to the facility

and accuracy of the process, combined with its comparative inexpensiveness, that the number of illustrated books has so greatly increased of late years. When all impressions had to be taken from the block itself, but few good ones could be obtained, as the wood-engraving rapidly wore out.

The intense heat of the electric arc causes it to be extensively used in the reduction of metals from their ores. Even the most refractory yield to this treatment, but the current required in order to produce the necessary amount of heat, often attains several thousand ampères, the electro-motive force being, however, quite low. Currents of the same kind are also used for the fusion of metals with high melting-points, and for welding, complete success having been attained even with aluminium, though all other means proved inadequate. For welding, however, it is not the electric arc which is used, but what may be called an "incandescent" method. The ends of the two pieces of metal to be welded are pressed together and the current passed through them, when the resistance it encounters at the point of contact, causes the development of a heat sufficient to soften the metals, so as to allow of their being easily united.

The best known and most important practical appliances of electricity have now been touched on,

but there are many minor uses (some of which should perhaps hardly be called minor,) which deserve at least mention.

In the first place, attempts are increasingly made, and with increasing success, to use electric currents as curative agents,¹ and there can be little doubt that, as the natural electrical condition of the human body becomes better understood, they will prove of the utmost importance for medical purposes. Paralysis and kindred diseases are very frequently treated by electricity now ; but no such course should ever be pursued except by the advice, and under the direction of a properly qualified medical practitioner who has made a study of the subject. Amateur attempts, when not positively dangerous, are far more likely to result in harm than good to the patient for whose benefit they are intended. Besides paralysis, certain kinds of tumour and aneurism have been cured by means of electricity. For this purpose electrolysis is employed ; it sets up chemical processes in the affected parts which result in the dispersion of the tumour or the hardening of the aneurism.

There is a hope that by means of a recent invention, electrolysis may be utilised for a yet more important purpose than the cure of disease, viz. its prevention on a large scale through ridding sewers

¹ Induction currents are most frequently employed.

of their poisonous gases, and thus rendering them innocuous. Electric currents have been also experimentally applied with some success to agriculture.

From these beneficial uses, it seems sad to turn to the destructive purposes which electricity is made to serve in warfare. It is now almost the sole agent employed for firing submarine mines and torpedoes, and many most ingenious contrivances have been devised, enabling an operator on shore to explode a mine some distance out at sea, at the very moment an enemy's vessel is passing over it.

Besides lighting, electricity is made to serve various domestic purposes. Electric bells are now so common and so evidently superior to all other kinds, that they will soon have no rivals left. Electric alarms are also frequently used in large establishments, and in some cases electrically-controlled clocks. There seems indeed no end to the ways in which man may employ this marvellous and ubiquitous agent, so mighty in its resources and yet so easily controlled. It has even been hoped that by its means vision, as well as speech, might be reproduced at a distance, and in fact some partially successful experiments in this direction, were made more than ten years ago by Professors Ayrton and Perry. The problems to solve are so many and so intricate, however, and the constructive difficulties to be overcome so great, that

it hardly seems possible an invention should ever be made which would be to the eye what the telephone is to the ear. Nevertheless, the marvellous adaptations of applied electrical science have astonished us so often, that it may well be another surprise is in store for us here.

CONCLUDING CHAPTER

“WHAT IS ELECTRICITY?”

Impossibility of giving a categorical answer to the question—
Analogy with the case of gravity—Our knowledge of electricity
in reality greater—Possible connection between the two sets of
phenomena—Important results achieved by electrical science
—Connection between electricity and light—Electro-magnetic
disturbances propagated through space with the velocity of
light—Space not empty—The ether—Meaning of radiation—
Of “radiant” heat, light, and electricity—Electro-magnetic
theory of light—Undulatory theory of light—Experimental
proofs on which it rests—Necessity for similar proof in the
case of electro-magnetic undulations—Hertz’s experiments—
Their conclusive result and consequent immense importance
to physical science—Concluding remarks.

To the question “What is Electricity?” it is impossible as yet to give any certain answer—as impossible as to say what the force of gravity is; for though the fact is perhaps not generally realised, we know as little of the nature of the one agent as the other. We say that “electricity” or electrified bodies “attract”; we say that gravity is a force of

attraction ; but neither of these assertions is an explanation, it is simply a statement of facts. In reality more is known about electricity than about gravity, for it is ascertained to some extent in what way the electrical forces are propagated, whereas with respect to gravity, we are absolutely ignorant as to its manner of working. We simply know that its observed effects are governed by unalterable laws, and it may perhaps be said, that the only hope of discovering anything further respecting its action, lies in the direction of there being found a connection between the phenomena of gravity and those of electricity, a possibility which gives a yet additional interest both to the experimental and theoretical study of the latter. Already a great part of the domain of physics, and nearly all that of chemistry has been revolutionised by the growth of electrical science, and if somewhat extravagant expectations are entertained about its future possibilities, they seem justified by the achievements it has already made.

In the present work but little has been formally said respecting any theory as to the nature of electricity, but it has been intimated that the electrical forces are propagated through the ether, and that there is a very close connection between electricity and light. To the observations already made,

it may be added that certain substances, notably selenium, have their electrical resistance very considerably altered if exposed to the action of light, also that a polarised ray of light in a strong magnetic field, has its angle of polarisation twisted into a different position.¹ But by far the most important point of connection between these two mysterious agents, light and electricity, is that the velocity with which an electro-magnetic disturbance is propagated through space, is equal to the velocity of light, being in round numbers, 186,000 miles a second.² Travelling at this rate light takes eight minutes to reach the earth from the sun, and the fact of its thus requiring time to travel, is sufficient to show us that space is not, as it is so often supposed to be, empty, but that there is something present in it which transmits light, and we may add, transmits also heat and electricity. The structure of this something, which it has been agreed to call "ether," is now, and perhaps always will be, unknown, but it is understood that it must be totally different to that of any other form of matter with which we are acquainted, though it appears to possess what may be called the counterparts of ordinary material qualities, such as elasticity and density.

¹ See note at the conclusion of the chapter, p. 300.

² By an electro-magnetic disturbance is meant such a disturbance as is given rise to, for instance, by the discharge of a Leyden jar, or the make and break of a galvanic circuit.

Heat, light, and electrical energy are propagated through this medium in a way known as *radiation*, i.e. in spherical waves. The term "radiant heat" is becoming familiar even to the non-scientific, but it must not be supposed that it designates any particular kind of heat. It simply means heat travelling in a particular kind of way, during which it does not appear as heat at all, but as motion; and the same is true of light and of "radiant" electricity. There is no light, as we understand light, except where the presence of gross matter modifies the action of the ether; the interplanetary and interstellar spaces are dark. Neither is there any sensible manifestation of heat or of electrical energy. But there is motion; and this motion is capable, under the right circumstances, of appearing either as light or heat or electrical energy.

If, however, light and electrical undulations are propagated through the same medium with the same velocity in the same manner, it is not difficult to conceive that they must be more than merely related; they must be to a great extent identical. This has been recognised by advanced scientific thinkers since the time—now more than twenty-five years ago—when the great English physicist and mathematician, Clerk Maxwell, published his *Electro-Magnetic Theory of Light*, of which the first experimental proof was given in 1877 by Professors Ayrton and Perry, who

found that the ratio of the electro-magnetic to the electro-static unit of electric quantity¹ was equal to the velocity of light, as Clerk Maxwell had shown that it must be, if light were propagated as an electro-magnetic disturbance. In 1888 another great step was made, for the existence of electro-magnetic waves, in all respects similar to those of light, was detected by direct experiment, and that date consequently marks a memorable era in the history of modern science. In order that the reader may be enabled to comprehend the nature of these now celebrated experiments, first carried out by a young German physicist named Hertz, and since him by others, reference must be made to what is known as the "undulatory theory" of light, and to the proofs on which it rests.

For a very considerable time it has been understood that light is caused by motion of some kind. The question was whether that motion was one of material particles shot out from the luminous body, as Newton supposed, or whether it was a vibratory movement started by the luminous body in the ether, through which it was propagated. The latter theory was always found by far the most capable of explaining luminous phenomena, and experimental proof of it was finally given by two eminent scientific men,

¹ Generally known as "v."

Young and Fresnel, the one English and the other French, independently. Connected with any wave movement, there is a phenomenon called interference, which is caused by the action of waves on each other, and which can be roughly observed by any one watching water-waves turned back from a sea-wall upon those still advancing. It will be noticed that the direct and reflected waves meet each other in one of two ways, either crest joins crest and furrow furrow, with the result of making a much larger wave, or crest joins furrow and furrow crest, and there is a patch of comparatively calm water. A much better way of observing the effects of interference is to suspend a cord to the ceiling of a room, and taking the free end in the hand impart to it a series of periodical impulses. Waves are thus given rise to in the cord which run up to the ceiling, are there reflected, and return to the hand of the operator, and while this is going on, if the rate of motion of the hand be right for the length and mass of the cord, the latter will divide itself into a regular succession of loops, the centre of each one of which is a point of greatest amplitude of vibration, *i.e.* where the swing of the cord particles from side to side is widest, while between each loop is a point of no vibration, technically called a node. Where the loops occur, the direct and reflected waves meet

each other in what is called the same phase of vibration (supposing they were water-waves; both would be rising and both falling at the same time); where the nodes occur, they meet in opposite phases of vibration (in water-waves one would be rising and one falling), so that the same point being acted on by two equal and contrary forces, remains at rest.

Now, if light travels in waves, wherever direct and reflected waves of light meet each other, there must be a similar phenomenon to that exhibited in the cord, and it can be observed by causing two pencils of red, or of any monochromous light to pass through two small apertures into a darkened room, and fall upon a white screen in such a way that certain portions of it are illuminated by reflected rays from both pencils, care being taken, as regards each pencil, that only light of one phase should reach the illuminated parts of the screen. There then appear on the latter alternate bands of the coloured light and of darkness, which correspond exactly to the loops and nodes in the cord, the coloured bands being caused by those light-waves which meet in the same phase of vibration, and the dark by those which meet in opposite phases. That this is really the case can be proved by shutting off the light from one of the pencils, when the dark bands disappear, thus showing that they were caused by interference. This experi-

ment places beyond a doubt the truth of the undulatory theory of light; and in order to prove the electro-magnetic theory of light, or in other words, the existence of electro-magnetic undulations identical with those of light, an experiment of the same kind, but of an electrical nature, was necessary.

The difficulty lay in the extraordinary rapidity of vibration which it was necessary to attain, in order to procure waves manageable within the walls of a laboratory. The ordinary oscillations of a Leyden jar discharge, which are at the rate of one million a second, were far too slow, for the ether wave length corresponding to this period (*viz.* the millionth of a second,) is 300 metres, and one of a few feet only was required. To obtain this it was necessary to produce vibrations of the order of 100 million per second, and even when this difficulty had been surmounted, by the construction of a special apparatus whose capacity, resistance and self-induction were so proportioned as to give vibrations of the required rapidity, there remained the question, how could they be observed? They could not be seen. Ether-waves which can be seen are waves of light, and their rate of vibration is several billion times a second. They could not be heard. To render them audible they must be made very much slower, as was done by Dr. Oliver Lodge in the experiment

described in Chapter iv. of Part III. In order to observe electrical waves too long to be seen, and too short to be heard, Hertz made use of the principle of resonance, the most familiar example of which is that of a tuning-fork, which when sounded is able to make any neighbouring tuning-fork of the same pitch as itself sound also, simply because their periods of vibration being the same, the second tuning-fork absorbs the vibrations of the first, and gives out exactly similar ones. Hertz therefore constructed two electrical circuits whose periods of vibration were identical. One he called the oscillator, and the other the resonator. The latter included a small spark gap, and was placed between the oscillator and the wall. When vibrations were set up in the oscillator, induced vibrations were set up in the resonator, and in a darkened room an infinitesimal spark was seen to cross the gap. By moving the resonator about to different parts of the room, Hertz found that in some places the sparking was more active, and in some it ceased altogether, and he also found that these spots of electric activity and repose succeeded each other at regular intervals, thus showing that they were due to the interference of direct and reflected waves, and were in fact a phenomenon exactly similar to the nodes and loops in the cord, and the dark and light bands described above. By

further developments of his experiment Hertz was able to prove that these electro-magnetic waves are transverse like light-waves, viz. that the vibrations take place across the line of propagation ; and moreover, that every effect which can be observed with the one kind of waves can be observed with the other. Thus both alike can be reflected, refracted, and polarised. Nothing is therefore wanting for the complete establishment of the "electro-magnetic theory of light." Electrical, like luminous phenomena, are all referable to the action of the ether, and we may say either that electrical science includes the whole of optics, or that optics includes the whole of electrical science, whichever way we like to put it. This is the commencement of a very splendid generalisation. It is without doubt one of the most important advances in physical science which has ever been made, and it is with a feeling of intense expectation that the question arises in our minds, "What will be the next?" Scientific men seem trembling on the verge of some discovery which will come nearer to the solution of the problems surrounding the ultimate nature of matter, than even a few years ago was deemed possible. Will this discovery be made in our own generation, or in the next, or perhaps not for many more to come? We cannot tell. At any moment it seems possible, and yet it may be

long deferred; but present knowledge would lead us to suppose that when it does come, it will be as amazing in its simplicity as in the depth and wideness of its scope. Already some of our leading physicists are beginning to formulate the query,—infinitely more far-reaching than that which heads this chapter,—whether all existing things are not modifications of that ether, but a short time since deemed hypothetical, and which is now proved to be the medium through which we receive the life-giving and life-sustaining energy emanating from the sun. Startling as such an idea may be at first sight, there is an inexpressible grandeur in the conception which it leads us to form of the unity of design pervading the whole of creation, and of that Infinite Mind which human reason,—its faint reflection,—is being more and more taught to realise as underlying and interpenetrating the “material universe.”

NOTE ON THE POLARISATION AND MAGNETISATION OF LIGHT.

It was mentioned in the preceding chapter that the vibrations of light are of the transversal kind, *i.e.* that they take place across the line of propagation, and in a ray of ordinary light, they are executed *in all directions* across this line. If, however, such a ray be caused to pass through a thin slice of tourmaline, or a Nicol's prism, it emerges with all its vibrations reduced to one plane, and is in the condition known as that of *plane polarised light*, the tourmaline, or Nicol's prism through which it has passed being called the *polariser*. The plane of polarisation can be discovered by placing a second slice of tourmaline, or Nicol's prism, called the *analyser*, in the path of the polarised ray, for a position can be found for the analyser, in which it is opaque to the incident polarised ray, whose light is consequently quenched altogether. This position is always at right angles to that of the polariser, to

the plane of polarisation of the ray, and to the position in which the analyser would itself polarise light.

By the "magnetisation" of light discovered and named by Faraday, the following effect is meant. If a bar of a certain kind of "heavy glass"¹ be placed across the poles of a powerful electro-magnet, and a ray of polarised light caused to pass through it, and enter an analyser on the opposite side, it is found that when the current is passing through the coils of the electro-magnet, the position in which the analyser causes darkness to occur, is not the same as when there is no current. This shows that the plane of polarisation of the ray has been twisted round under the magnetic influence, and proves a direct action of magnetism on light. The direction in which the plane of polarisation is twisted, is for most diamagnetic substances the same as that of the magnetising current, but for many magnetic substances, contrary to it. Further proof of the rotatory effect produced by magnetism on light is given by the fact that a polarised ray reflected from a magnet or an electro-magnet also has its plane of polarisation twisted round. If the reflection takes place from a pole, the

¹ A tube containing bi-sulphide of carbon will have the same effect, which can also be produced in a minor degree by other substances, and to a very small extent by air.

plane of polarisation is turned in a contrary direction to that of the flow of the magnetising current, if from a point at the side of the magnet, in the same direction, provided the planes of incidence and polarisation are parallel. If they are perpendicular to each other, the direction of rotation is only the same as that of the magnetising current if the angle of incidence exceeds 75° . For lesser angles the rotation is opposite to the direction of the current.

INDEX

- ABINGDON, thunderstorm at, 93
 Accumulator, 43, 232, 233, 246
 Aclinic line, 131
 Action, of points, 14 ; chemical, 37 ; in galvanic battery 145 ; in voltameter, 159 ; and reaction of currents, 185
 Agonic line, 129
 Air, an insulator, 13 ; discharge through rarefied, 21 ; electrical condition of, 62 ; medium of transmission of sound, 79
 Alarums, 287
 Aluminium, welding of, 285
 Amber, 3
 Ampère, *memoria technica* of, 167, 172 ; laws of, regarding interaction of currents, 186 ; table of, 186, 187 ; the, 203
 Analogy between potential and level, 32
 Analyser, the, 300
 Anions, 157
 Anode, the, 157, 283
 Antimony, junction between, and bismuth, 153
 Applicances, practical, 206 ; miscellaneous, 286
 Arago, 179
 Arc, voltaic, 223
 Area, unit of, 30
 Armature, 209 ; cylindrical, 210 ; drum, 216 ; disc, *ib.*
 Atmosphere, electrical condition of, 61
 Atoms, combination of, 2 ; procession of charged, 156, 157 ; deposition of metallic, 157, 282
 Attraction, 2 ; electrostatic, 4 ; magnetic, 117 ; laws of, between currents, 171
 Aureole, 192
 Aurora, Borealis, 67, 68 ; Australis, 69 ; elevation of, 88
 Ayrton and Perry, electroscope of, 35 ; clock-meter of, 240 ; telephage introduced by, 247 ; experiments on electric transmission of vision by, 287 ; experimental determination of "v" by, 293
 BALANCE, the induction, 277
 Bath, the, for electro-plating, 283
 Battery, of jars, 48 ; galvanic, 139, 142 ; polarised, 145 ; principle common to every galvanic, 147 ; storage or secondary, 148 ; floating, 173
 Bell, electric, 242, 287
 — receiver, the, 273
 Biot's experiment, 28
 Bismuth is diamagnetic, 116 ; used in thermopile, 153
 Blake transmitter, the, 273
 Bunsen's cell, 146

- C.G.S. system, the, 198
 Cells, 139, 140 ; in series and in parallel, 141 - 144 ; constant, 145, 146 ; electrolytic, 157, 283
 Centimetre, 198
 Changes, chemical, caused by discharge, 56, 84
 Charge, induced, 11, 12 ; by conduction, 12 ; seat of, 28 ; cause of, 30 ; residual, 46
 Chemical action. See Action
 Chimes, electric, 18
 Chinese and the magnet, 130
 Circuit, a, 53 ; closed voltaic, 174 ; sparks on making and breaking, 191, 192 ; resistance of, 200 ; earth, 254
 Clarke's machine, 209
 Clouds, potential of, 62, 64 ; electrified throughout, 71 ; altitude of thunder-, 88
 Coils of galvanometers, 168 ; of electro-magnets, 180 *seq.* ; resistance, 200 ; of field magnets in dynamos, 217
 Columbus, 130
 Commutator, the, 215, 256
 Compass, the mariner's, 130 ; the inclination, 131 ; standard, 137
 Compound-wound dynamos, 218
 Condenser, 43 ; air-, 46
 Conductors, 8 ; non-, 9 ; discharge of, 10 ; pointed, 14, 101 ; prime, 17 ; lightning, 22, 101, 262 ; insulated, 24 ; potential of, 32 ; capacity of, 42 ; effect of charged, 56 ; rotation of liquid, 177
 Connection, earth, 43, 103
 Contact between metals, 37 ; -breakers, 191
 Convection, 156
 Cooke's telegraph, 253
 Core of electro-magnets, the, 179, 182, 183, 184
 Coulomb, law of, 5 ; the, 203
 Cuneus of Leyden, 44
 Currents, electric, direction of, 139 ; cause of, 141, 142 ; energy of, 148, 150 ; thermo-electric, 153 ; chemical effects of, 155 ; strength of, 159, 200 ; physiological effects of, 161 ; galvanic, 163 ; magnetic effects of, 165 ; amperian, 175 ; induction, 182, 187, 195 ; higher order of, 196 ; measure of, 197 ; dynamo, 220 ; accidents from, 235 ; telegraphic, 264 ; telephonic, 273 ; as curative agents, 286
 DANIELL'S cell, 146-264
 Davy, Edward, 254
 — Sir H., 157 ; voltaic arc, 223
 De la Rive, 173
 Declination of the needle, 126, 135 ; map, 129 ; compass, 130
 Decomposition, chemical, by current, 140, 156
 Deflections of magnetic needle, 165, 166, 167
 Density of electricity, 30
 Diamagnetism, 117
 Dielectrics, 42, 144
 Difference, potential, defined, 32 ; in inductors of influence machines, 33 ; in batteries, 142
 Discharge, glow, 20 ; brush, 20, 80 ; luminous, 21, 192, 194 ; of Leyden jar, 22, 45, 49 ; between clouds, 72
 Distance, the sparking, 50
 Disturbances, electro-magnetic, 129
 Dogcart, electric, 247
 Drigg fulgurites, 85
 Drops, electrified, 64
 Duplexing, 205
 Dust figures, 55
 Dynamo machines, 210, 211 ; magneto and self-exciting, 212 ; alternating, 215 ; continuous-current, 215, 233 ; requisites for, 217 ; driving of, 245

- EARTH, connection, 103 ; a magnet, 127 ; currents, 133, 276
- Edison lamp, 227
- Effects, luminous, 19, 22 ; mechanical, 54 ; of evaporation, 63 ; electrical in New York, 64 ; of rupture on magnet, 123 ; of earth's magnetic force, 134 ; chemical, 155 ; physiological, 161, 286 ; magnetic, 165 ; rotatory, 176, 301 ; of induction on telephone, 276
- Electric light, arc, 223 *seq.* ; incandescent, 227 *seq.* ; harmless, 235 ; advantages of, 235, 236 ; rich in chemical rays, 236
- Electricity, static, 1 ; atmospheric, 2, 20, 57, 70 ; kinds of, 5-8 ; bound, 11 ; distribution of, 32 ; thermo-, 37 ; current, 37, 83 ; cause of manifestation of, 38 ; source of atmospheric, 62 ; variations of atmospheric, 63 ; current of defined, 139 ; for street traffic, 147 ; practical appliances of, 206 ; a light-producer, 222
- Electrics, 3, 9
- Electrode, 140, 156
- Electrolysis, 157, 283, 286
- Electrolytes, 157
- Electro-meters, 34
- Electro-metallurgy, 283, 285
- Electro-motors, 207, 218
- Electron, 3
- Electrophorus, 24, 33
- Electroplating, 282
- Electroscope, 34
- Electrotyping, 284
- Elements, magnetic, 131 ; of battery, 139
- Energy, of lightning, 105 ; storage of electrical, 148 ; transmission of, through insulating medium, 150 ; waste of, in heat, 195, 209, 217 ; distribution of electrical, 233 ; measurement of, 239
- Engineering, electrical, 219
- Equator, magnetic, 47
- Eruptions, volcanic, 89
- Ether, the, 47 ; medium of transmission of light, 79 ; of magnetic forces, 120 ; properties of, 291 ; function of, 298
- Evaporation, 63
- Experiments, 10, 28, 29, 44, 45, 46, 52, 54, 58, 59, 60, 64, 83, 268
- FARAD, the, 204
- Faraday, 29 ; on insulating medium, 31 ; discoverer of induction currents, 187 ; on magnetisation of light, 301
- Faults, telegraphic, 261
- Faure's storage battery, 147
- Fibres, bamboo, thread, 228
- Field, magnetic, 124-126, 172, 183, 184
- Filament, carbon, 228
- Fire, St. Elmo's, 20
- Flashes, lightning, cause of, 78, 79 ; length of, 88 ; causes of, 106
- Flashing, 229
- Fluctuations, magnetic, 133
- Fluorescence, 193
- Fog, electric, 62
- Force, magnetic, 117, 128 ; lines of, 125, 184 ; coercive, 135 ; electro - motive, 143, 144 ; thermo-electro-motive, 153, 199 ; measurement of, 198
- Fox, Lane (lamp), 228
- Franklin, theory of, 6 ; discovery of action of points, 14 ; on thunder and lightning, 57
- Fresnel, on light, 293
- Friction, 10 ; analogy with resistance, 55, 144
- Fulgurites, 85, 86
- Fuses, safety, 233
- GALVANI, 139, 161

- Galvanometers, 168, 169 ; mirror, 170, 260 ; calibration of, 171
 Galvanoscope, 167
 Geissler's tubes, 21, 193 ; experiment on luminous discharge through, 194
 Gilbert, Dr., 3 ; his experiments, 4 ; error, 9 ; earth a magnet, 127 ; *De magnete*, 193
 Globules, Planté's luminous, 83, 84
 Glow, electrical, 222
 Gramme, the, 198 ; ring, 213-215
 Graphophone, the, 281
 Gravity, 289, 290
 Gröthuss' theory, 160
 Grove's battery, 146
 Guericke's, Otto von, machine, 15, 24
- HAIRPINS, electric, 237
 Harris's, Sir W. S., system of protection from lightning, 99, 102
 Heat, effects of, 4 ; development of, 22 ; a source of electricity, 37, 81 ; mode of travel of, 155 ; radiant, 292
 Heart, the, and lightning shock, 92, note
 Hertz, 293 ; his experiments, 297
 Hughes's printing telegraph, 258
 Humboldt, account of magnetic carriages, 130
- INCANDESCENT lamp, 227-230
 Inclination of the needle, 131
 Illumination, indoor, 232
 Induced charges, 14, 38
 Induction, electrical, 11, 12 ; cause of shock, 23 ; magnetic, 118 ; self-, 152, 190 ; of currents by currents, 187, 188 ; by magnet, 189 ; of currents in dynamos 211 ; in underground and submarine cables, 262, 263 ; in telephone wires, 276
 Induction-coil, 191 ; sparks from, 192
 Inductors, 33
 Inertia, 151, 152
 Instruments, telegraphic, 254, 255 *seq.*
 Insulation, 35 ; of electric-lighting wires, 234 ; of telegraph wires, 26, 262 ; submarine cables, 263
 Insulators, 8, 9
 Intensity, magnetic, 128
 Interference and its effects, 294, 295
 Inventions. See Guericke, etc.
 Ions, 157
 Iron, a magnetic substance, 116 ; magnetised and demagnetised, 124 ; used for core of electromagnets, 130
 Isogonic lines, 129
- JABLOCKOFF candle, 226
 Jar, the Leyden, 40, 163 ; discovered, 43 ; method of charging, 44, 45 ; oscillatory discharge of, 48, 49, 50, 296 ; when inclined to burst, 49 ; discharge of, 164 ; E. M. F. of, 204
 Jet, 3
 Joudpore powder-magazine, 101
 Judd, Prof., on electricity in volcanic eruptions, 90
- KATHIONS, 157
 Kathode, 157, 282
 Kew, 131 ; magnetic needle in 1851, 133
 Kite, Franklin's, 58
 Krakatoa, 89
- LAMINATED magnets, 121
 Lamps, arc, 225 ; illuminative power of, *ib.* ; incandescent, 227
 Launches, electric, 248
 Leclanché cell, 264
 Length, unit of, 37

- Lenz's law, 195
 Lichtenburg's dust figures, 55
 Light, incandescent, 126 *seq.* ;
 the arc, 224 *seq.* ; connection
 with electricity, 290 ; polarised
 ray, 291 ; caused by motion,
 293 ; note on polarisation and
 magnetisation of, 300
 Lighthouses, 224
 Lighting, electric, 222, 234 ; in-
 stallations, 225 ; currents for, 230
 Lightning, 10, 57 ; cause of, 71,
 78 ; characteristics of, 72 ; rods,
 ib. ; duration of, 73 ; colours
 of, 74 ; shape of forked, *ib.* ;
 path of, 75, 77 ; sheet, 80 ;
 globular, 80-83 ; summer, 81 ;
 chemical changes by, 84 ; heat-
 ing effects of, 85 ; explosions
 through, 87 ; magnetising power
 of, 88 ; at Krakatoa, 89 ; dangers
 from, 91, 96 ; protection from,
 91, 99, 101, 102 *seq.* ; destruc-
 tion from, 93 *seq.* ; energy
 developed by, 105
 Lines, isogonic, 129 ; isoclinic,
 131 ; of force, 125
 Living body, passage of electricity
 through a, 10, 164
 Lodestone, the, 112
 Lodge, Dr. O., experiments of,
 41, 52
 MACHINES, electrical, 11 ; effects
 of, 14 ; frictional, 15, 16 ;
 cylinder, 16 ; influence, 24 ;
 Wimshurst's, 26 ; Holz's, 27 ;
 magneto- and dynamo-electric,
 206 ; Siemens's, 213
 Magnet, natural, 111 ; origin of
 name, *ib.* ; permanent, 112 ;
 artificial, *ib.* ; ways of making,
 120 ; strength of, 122 ; lifting-
 power of, *ib.* ; compensating, 126 ;
 controlling, 170 ; electro, 181
 Magnetic needle, floating, 134 ;
 deflection of the, 165-167
 Magnetisation, of iron and steel,
 122, 135, 179 ; of light, 301
 Magnetism, 37, 111 ; two kinds
 of, 114 ; earth, 133 ; residual,
 179, 210 ; electro-, 180
 Magnetite, 112
 Magneto - electric machines, 207,
 208, 209
 Magnets, properties of, 115 *seq.* ;
 electro-, 178, 179 ; fixed or
 field, in dynamos, 211
 Map, declination, 129 ; magnetic,
 132
 Mass, unit of, 37
 Maxim lamp, 228
 Maxwell, Clerk, electro-magnetic
 theory of light, 292, 293
 Measurement of quantities, 198
 Medium, insulating, 13, 30, 150 ;
 dielectric, 47, 150
 Mega-volts, 203
 Megohms, 203
 Mercury, 156, 199, 202
 Meridian, magnetic, 127, 136
 Metals, contact series of, 37, 39 ;
 resistance of, 199 ; fusion of, 285
 Meter, volt-, am-, clock-, 240
 Micro-ampère, 203 ; -farad, 204
 Microphone, the, 271 ; insulation
 of the, 275 ; for medical use,
 278
 Milli-ampère, 203
 Mines, firing, 287
 Miophone, 278
 Moisture, influence of, 4, 35
 Molecules, 3
 Morse, 255 ; code, 256 ; sounder,
 259
 Muscle, contraction of, 162
 Musical notes, transmission of,
 268, 275
 NAVIGATION, aerial, 249
 Needle, magnetic, 55 ; dip of, 131
 Negative electricity, 6, 8, 17
 Nerve, the optic, effect of current
 on, 163

- Nitric acid, formation of, 85
 Node, a, 294
 Non-conductors, 9, 10, 156, 158
 Non-electrics, 3
 Norman's inclination compass, 131

 ØRSTED's experiments, 166, 253
 Oscillations of Leyden jar discharge, 48, 52; of lightning, 79; of magnetic needle, 128
 Oscillator, Hertz's, 297
 Ozone, 23; production of, 56, 59; active form of oxygen, 66; a chemical agent, 66; generated by lightning, 84

 PAIR, thermo-electric, 153; astatic, 169
 Paralysis, 286
 Perforation of cardboard, 54
 Phenomenon of recoil, 51
 Phonograph, the, 278-280
 Phosphorescence, 193
 Pixii's machine, 207, 208
 Planté, on the Aurora sound, 69; on globular lightning, 83; his storage battery, 149
 Platinum, 37; in Grove's battery, 146, 227
 Playford, storm at, 87
 Polarisation of battery, 140, 149; of light, 300; plane of, 301
 Pole, positive, 21, 140; negative, 21, 140; magnetic, 128
 Positive electricity, 5, 6, 11, 15; absence of, 66
 Potassium, 157
 Potential, 31; difference of, defined, 32; high and low, 32, 37; dependent on, 33; of the air, 61; of clouds, 62, 64; in galvanic battery, 63
 Power, definition of, 241; transmission of, *ib.*; loss in transmission, 243; requisites for electric transmission of, 244, 245

 Pressure, electric, 220
 Prism, Nicol's, 300
 Proof-plane, 29
 Protection from lightning, 106, 109; area of, 109

 QUADRUPLEX telegraphy, 264
 Quantity of electricity, alteration in, 12, 13; per unit of area, 30; measure of, 198-201

 RADIATION, 292
 Réaumur, 44
 Recoil, 51
 Recorder, the syphon, 260
 Reis, telephone of, 267
 Relationship between magnetism and current electricity, 174
 Relay, polarised, 157, 158
Repulse, the ship, 99
 Repulsion, 4; between magnets, 115; between currents, 185
 Requisites for good dynamos, 217
 Resin, 55
 Resistance, to oscillations, 51, 52; of lightning rods, 105; defined, 144; mechanical, 195; redefined, 199, 200; coils, 200, 238; boards, 238
 Resonance, 79, 297
 Resonator, Hertz's, 297
 Retentivity, 135
 Ritter, accumulators, 149
 Rods, lightning, 103, 104
 Romas, experiments of, 58
 Ruhmkorff's coil, 191
 Rupture of magnet, 123

 SACCO, lightning at, 93
 Sand, vitrified, 85
 Saturation of magnets, 121, 183
 Search lights, 224, 225
 Seat of charge, 28
 Second, the, 198
 Selenium, 291
 Series-winding, 217
 Shell, magnetic, 122

- Ships, struck by lightning, 99 ;
loss of, 136
- Shunt-winding, 217
- Siemens, 210 ; armature, *ib.* ;
self-exciting dynamo, 212
- Solenoid, 180-184
- Sound, rate of travel, 81
- Sources of electricity, 37
- Spark, electric, 19, 56, 222 ; from
induction coils, 22 ; from
Leyden jar, 45 ; duration of,
48 ; effect of light of, on charged
conductors, 78
- Speed of transmission of telegraphic
signals, 258
- Sphygmophone, 278
- Steeple-Ashton, ball of fire at, 95
- Steinheil, discoverer of earth-cir-
cuit, 254
- Storms, magnetic, 129 ; period-
icity of, 131
- Striæ, 22
- Storage, work of, 148 ; batteries,
148, 149
- Substances, magnetic, 116 ; dia-
magnetic, 117
- Suez Canal, lighting of, 237
- Sultan*, H. M. S., struck, 87
- Sun-spots, 133
- Swan lamp, 227, 228
- System, the C. G. S., 198
- Tanjore*, the, struck, 100
- Telegraph, the, 206, 250 *seq.*
- Telegraphy, duplex and quadru-
plex, 264
- Telephone, the, 267-271 ; ex-
change system, 273, 274
- Telpherage, 247
- Tetanus, 163
- Thales, 3
- Theory, molecular, of magnetisa-
tion, 123, 124 ; electro-mag-
netic, of light, 292, 296 ; un-
dulatory, of light, 295
- Thermopile, 153
- Thompson, Sir W., mirror galvano-
meter, 170, 260
- Thompson - Houston system of
lighting, 230-232
- Thunder, 57 ; cause of, 60, 81
- Time, unit of, 37
- Torpedoes, 287
- Tourmaline, 300
- Traction, electric, 219
- Tramways, electric, 245
- Transformers, 221, 232
- Translation, 255
- Tubes, Geissler's, 21, 193
- Tuning-fork, 79, 297
- Turpentine, 156
- UNDULATORY theory and proof,
293, 295
- Undulations, 293, 296
- Units, electrostatic, 36 ; electro-
magnetic, 37 ; practical, 197-
199 ; absolute, 198, 203, 204 ;
of power, 241
- Uranium glass, 193
- VACUUM, a dielectric, 47 ; dia-
magnetic, 120
- Velocity of light and electro-mag-
netic disturbances, 291
- Vermilion, 55
- Vibrations in Leyden jar, 52 ; of
tuning-fork, 79
- Vision reproduced, 287
- Volt, the, 202
- Volta, 37-39 ; his first battery,
251
- Voltameter, 158, 159
- WATER, dammed up, analogy with
an electric charge, 31 ; between
level of, and potential, 32 ;
between flow of, and current,
151 ; pure, a non-conductor, 158
- Watt, the, 241
- Waves, electro - magnetic, 293 ;
transverse, 297

-
- | | |
|---|---|
| Welding, 285 | Wires, overheated, 235 ; telegraph, 261 |
| Westbury Downs, storm at, 82 | Woolridge, Capt., at Krakatoa, 89 |
| "What is electricity?" 289 | Work, 32, 142-; unit of, 241 |
| Wheatstone's, Sir C., experiment, 54 ; self-exciting dynamo, 212 ; telegraph, 253 | YOUNG on light, 293 |
| Whirl, electrical, 19, 54 | ZINC, 37 ; sulphate of, 145. |
| Wilde's machine, 209 | |
| Windmill, electric, 18 | |

THE END

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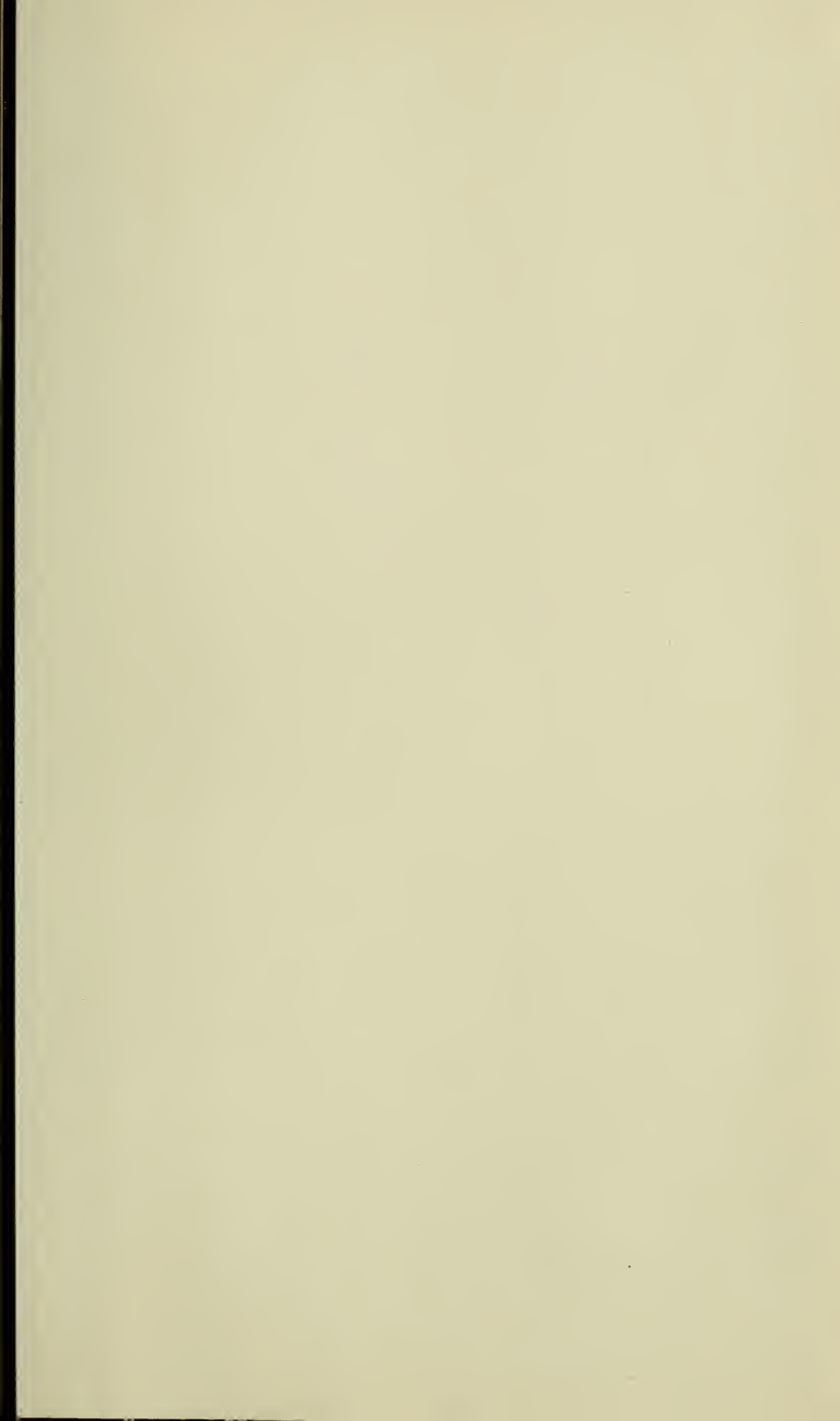
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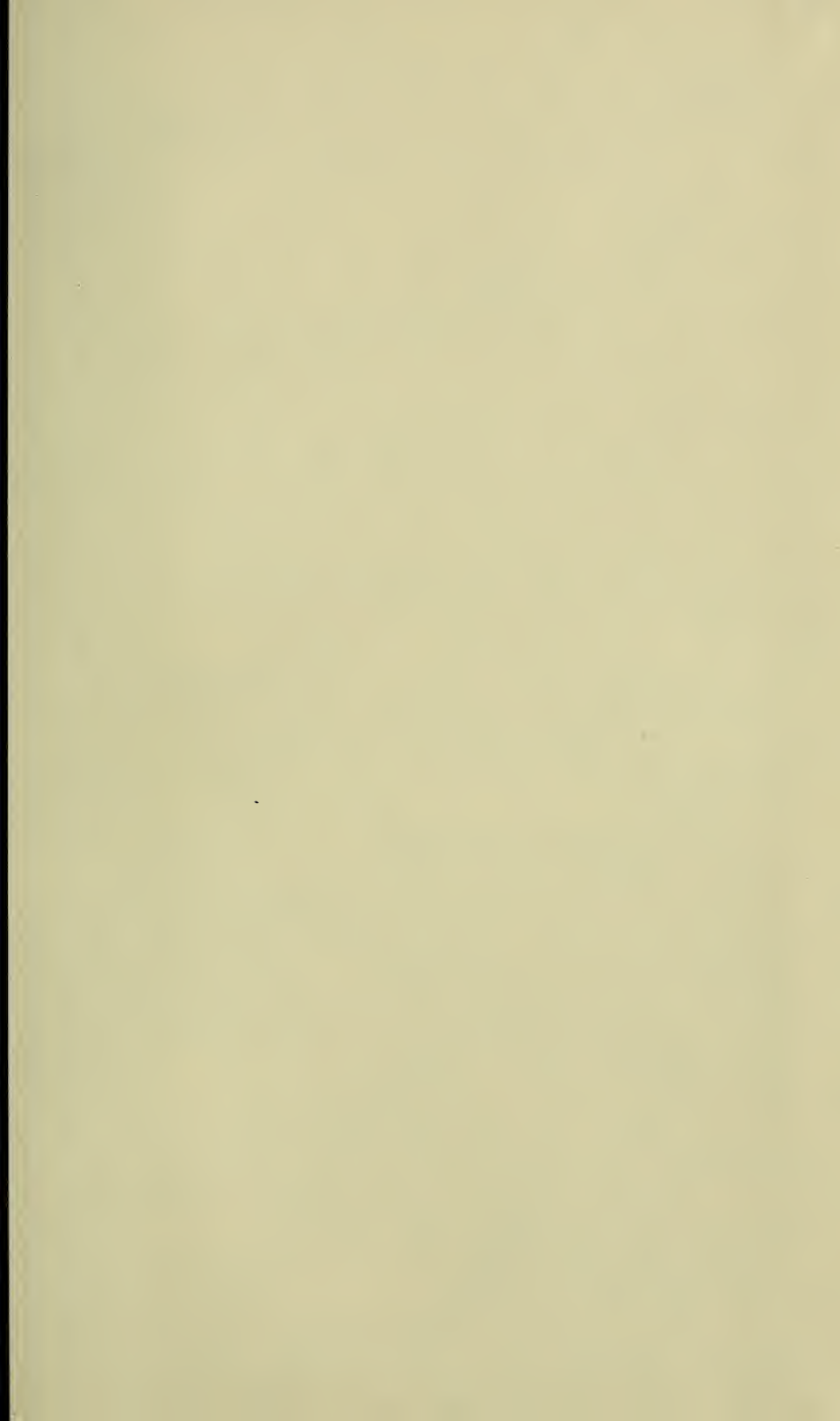
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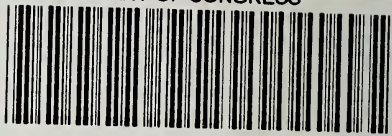








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